THE No 1 UK MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

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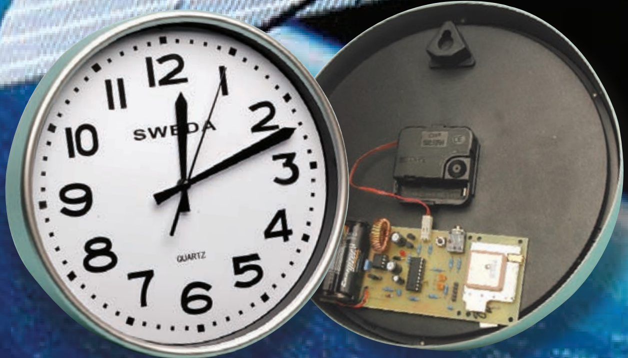


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# EPE EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL

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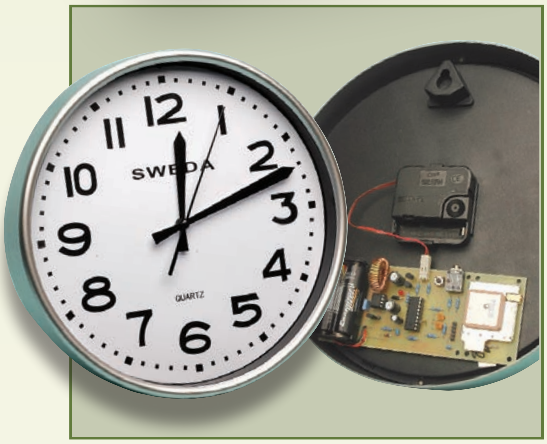


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## Series and Features



## Regulars and Services





*Our April 2011 issue will be published on Thursday 10 March 2011, see page 80 for details.*

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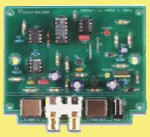

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**See website for more super deals!**

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# EVERYDAY PRACTICAL ELECTRONICS

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## The shape of things to come

Barry Fox, our resident technology journalist, has been to the 2011 Consumer Electronics Show (CES) in Las Vegas, and his report in the news pages on the future of accessing video content is fascinating reading. Barry picked on one aspect of the show, but it is well worth remembering that CES is a vast international event that touches on just about any technology that involves manipulating our old friend, the electron.

The figures speak for themselves; for example, more than 2,700 technology companies across global industries exhibited this year. 140,000 industry professionals attended, with 30,000 from abroad. It's a great place to spot technologies that have been brewing away in cosy research labs, but are now making their way into the harsh commercial world of big business.

The major technology trends that emerged from the CES show floor included the launch of more than 80 computing tablets, wireless 4G LTE technology, connected TV systems and electric vehicles. Ford's Alan Mulally unveiled the company's first electric car at the 2011 CES, with the Ford Focus Electric.

I am particularly looking forward to 4G, the fourth generation of cellular wireless standards, and successor to the 3G and 2G families. It should offer the kind of leap in speed reminiscent of moving from dial up to broadband, but this time on the move. (Whether or not wireless networks will be able to keep up with the resultant surge in data remains to be seen!)

I've never been to CES, but I went to Las Vegas when I was a very small boy (just nine year's old) in the summer of 1972. The world of electronics has been transformed since then. Microsoft and Apple were teenage daydreams in the minds of Bill Gates and Steve Jobs, and home computers were still science fiction. Let's hope the next four decades will bring innovations as exciting as these last four.



### AVAILABILITY

Copies of *EPE* are available on subscription anywhere in the world (see opposite) and from all UK newsagents (distributed by SEYMOUR). *EPE* can also be purchased from retail magazine outlets around the world. An Internet online version can be purchased and downloaded for just $19.99US (approx £13) per year, available from **www.epemag.com**


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# NEWS

### A roundup of the latest Everyday News from the world of electronics

## Downloads vs discs – a cloudy forecast? by Barry Fox

Visitors to the *Consumer Electronics Show* (*CES*) in Las Vegas in January would be excused thinking that the future of movie viewing lies in downloading and the end is nigh for physical movie media such as DVD/Blu-ray. But the reality may be different.

'Total freedom of entertainment', is what the Digital Entertainment Content Ecosystem (DECE) promises from its new cross-platform download standard called UltraViolet. 'One simple powerful system that puts you in charge will redefine how you watch'.

'Beginning mid-2011, consumers will be able to experience UltraViolet' declared DECE, promising 'a roadmap for introducing UltraViolet content, services and devices to consumers beginning in mid-2011, with planned expansion to the UK and Canada, and the release of technical specifications for evaluation by potential licensees.'

The system 'launch' event at CES featured a panel discussion with top-level executives from Hollywood and the IT and electronics industries. Their discussion was moderated by an apparently non-technical reporter from the *Los Angeles Times*, who left loose ends untied and took no audience questions.

The DECE's PR squad was on hand to block any attempt at interviewing the panellists afterwards. Whether by intent or clumsy accident, the organisers failed to identify the panellists with name cards!

DECE promises that 'UltraViolet will allow consumers to purchase digital content and watch it wherever, whenever.'

'UltraViolet will launch with movies and TV shows in mid-2011' says Mark Teitell, general manager and executive director of DECE, admitting that the concept of downloading movies has so far failed to catch on and needs a 'do-over'.

'The UltraViolet logo tells people they have the right to enjoy what they buy', he says. 'All they will have to do is set up a free account, with no credit card needed, to create a library for 'my UV collection'. They can use what they buy on 12 devices, and remove old devices from the account to add new ones. By the end of 2011, there will be a common file format that allows WiFi sharing round the house. Consumers will see the UV logo on discs and on the World Wide Web.'

Thomas Gewecke, president, Warner Bros Digital Distribution, thought that consumers would feel confident knowing that 'everything comes with a copy on the cloud' and 'people will move from wanting something physical to wanting access to a digital locker'.

He did not address the fact that for Joe Public, a 'cloud' is something that is constantly changing.

Although DECE has 60 members, Apple and Disney are notably not among them. Jean-Briac Perrette, president, Digital and Affiliate Distribution, NBC Universal, feels confident that Disney 'will come in' and in the case of Apple 'it is them versus everyone else'.

The other possibility – ignored by the panel – is that Apple could license its proprietary DRM so that non-Apple devices can work with iTunes.

Chris Homeister, senior vice president and general manager, Home Entertainment Group, Best Buy, admitted that 'the technical specifications are just being finished' and Tae-Jin (TJ) Kang, senior vice president, Media Solution Centre, Samsung Electronics, confirmed: 'Our roadmap for 2011 is already set, so we are now planning for 2012. With mobiles we have to work with the carriers. So we have not set dates or plans'.

## Security risks of weak passwords and PINs

A combination of poorly-chosen passwords and weak authentication security is putting Internet users at risk of a serious security breach, according to security experts at Corsaire. In fact, although many people believe that the latest security solutions being employed in areas like e-commerce and online banking will protect them from fraudsters, this may not always be the case.

For Internet users, the process of authentication is typically achieved with the submission of a username and password. In some cases, users are also required to enter additional personal information (such as date of birth) or to enter a selection of digits or characters from a second 'secret' value.

Unfortunately, however, many password policies still do not include this 'second tier' of security, nor do they attempt to encourage some form of complexity within password selection. For example, many systems allow the user name and password to be the same, while others allow very short passwords to be used.

According to Corsaire, one of the weakest passwords for online transactions is the PIN, especially if a customer is using the same PIN with both a cashpoint card and for online banking. Not only is a PIN a weak authenticator because of its short numeric value, but users may also be tricked into disclosing their PIN to a third party, which could expose the 'physical' card to the possibility of a 'virtual' attack.

'Using the PIN from your cashpoint card as an online password is a very bad idea from a security point of view, and should be avoided,' says David Ryan, associate principal security consultant with Corsaire's Security Assessment Team. 'PINs are arguably secure in the real world as they are used in closed systems with strict lockout criteria, but these benefits are lost when these same credentials are used online.'

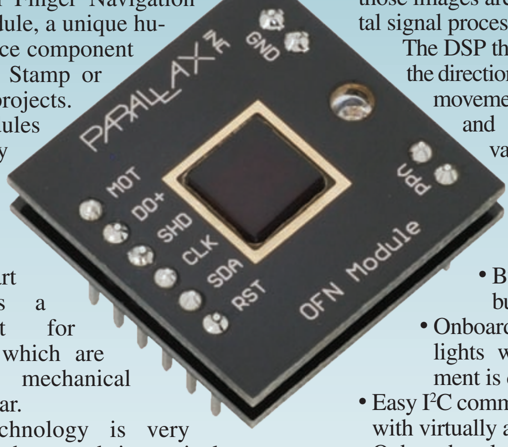
Instead of encouraging their online customers to use a PIN or a simple password, Corsaire has been urging banks and other organisations to implement password policies that are based on minimum character lengths, and which include reasonable complexity. This can provide a solid, inexpensive way of authenticating users, but only if the policy on passwords is being enforced, and if users are given guidance on what is a strong password.

Multi-word 'passphrases' should also be promoted in place of passwords, according to Corsaire, in order to make attacks from online criminals more difficult. The main advantage a passphrase has over a password is that the length can be significantly increased, without making the password overly complex, and can thus increase the overall strength of the user's password by multiple factors.

In recent reports, Mr Ryan has revealed how a weak online 'identity' can have a cascading effect on the remainder of the security system. If an attacker can identify users of the system (by using someone's email addresses as his 'user name', which is now a common practice), they may be able to mine public data sources, such as search engines and social networks, to identify personal details, preferences and other pieces of data that may be useful in breaching the security of the system. Personally identifiable data (PID), such as date of birth, telephone number and other pieces of information should also be avoided for authentication purposes, since this kind of personal data can be easily discovered via both online and offline means.

*See* Techno Talk *for more 'horror stories' on Chip-and-PIN.*

# Optical Finger Navigation module released




Parallax have released their new Optical Finger Navigation (OFN) Module, a unique human interface component for BASIC Stamp or Propeller projects. OFN modules are quickly becoming popular as user input devices in many smart phones as a replacement for trackballs, which are subject to mechanical wear and tear.

OFN technology is very similar to that used in optical mice, and movement across the sensor can be read by any microcontroller using $I^2C$ communication.

When a finger moves across the surface of the OFN module, an onboard LED is activated to light up the surface of the finger. The onboard 'image acquisition system' then obtains microscopic images of the finger surface, and those images are processed by the DSP (digital signal processor).

The DSP then mathematically determines the direction and magnitude of the finger's movement and calculates the delta-x and delta-y relative displacement values. A microcontroller can then read these values using simple $I^2C$ communication.

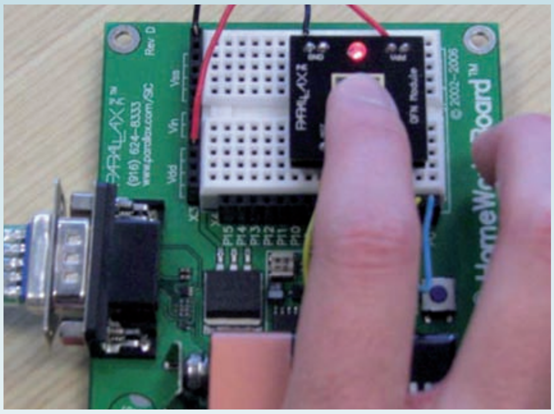
OFN technology features include:

- Built-in centre select button
- Onboard red LED, which lights when finger movement is detected
- Easy $I^2C$ communication interface with virtually any microcontroller
- Onboard voltage regulator conditions I/O to 3V maximum for compatibility with 3.3V devices, even when 5.5V is supplied.
- User-selectable 500 to 1000 counts per inch (cpi) resolution
- User-definable 0 or 90° module orientation
- Breadboard-friendly package with 0.1-inch pin spacing

OFN application ideas include, but are not limited to:

- Video game input
- Mouse replacement
- User input for computing devices

For further information and data sheets, visit: **www.parallax.com**.



*The new Parallax OFN module*

## Moving holograms: from science fiction to reality

A University of Arizona team has developed a new type of holographic telepresence that allows the projection of a three-dimensional moving image, without the need for special eyewear such as 3D glasses or other auxiliary devices.

Remember the *Star Wars* scene in which R2D2 projects a three-dimensional image of a troubled Princess Leia delivering a call for help to Luke Skywalker and his allies? What used to be science fiction is now close to becoming reality thanks to a breakthrough in 3D holographic imaging technology developed by the College of Optical Sciences.

It is claimed that the technology is likely to take applications ranging from telemedicine, advertising, updatable 3D maps and entertainment to a new level.

The prototype device uses a 10-inch screen, but researchers are already successfully testing a much larger version with a 17-inch screen. The image is recorded using an array of regular cameras, each of which views the object from a different perspective. The more cameras that are used, the more refined the final holographic presentation will appear.

That information is then encoded onto a fast-pulsed laser beam, which interferes with another beam that serves as a reference. The resulting interference pattern is written into the photo-refractive polymer, creating and storing the image. Each laser pulse records an individual 'hogel' in the polymer. A hogel (short for holographic pixel) is the three-dimensional version of a pixel, the basic units that make up the picture.

The hologram fades away by natural dark decay after a couple of minutes or seconds depending on experimental parameters. Or it can be erased by recording a new 3D image, creating a new diffraction structure and deleting the old pattern.

Currently, the telepresence system can present in one colour only, but the team have already demonstrated multi-color 3D display devices capable of writing images at a faster refresh rate, approaching the smooth transitions of images on a TV screen. These devices could be incorporated into a telepresence set-up in near future.

## Firefox overtakes Internet Explorer in Europe

Firefox overtook Microsoft's Internet Explorer to become the number one browser in Europe in December 2010, according to StatCounter, the free website analytics company. The firm's research arm StatCounter Global Stats reports that in December, Firefox took 38.11% of European market share, compared to IE's 37.52%.

'This is the first time that Internet Explorer has been dethroned from the number one spot in a major territory,' commented Aodhan Cullen, chief executive, StatCounter. 'This appears to be happening because Google's Chrome is stealing share from Internet Explorer, while Firefox is mainly maintaining its existing share.'

## EMOTIONAL COMPUTERS

*Having a computer that can read our emotions could lead to all sorts of new applications, including computer games where the player has to control their emotions while playing.*

*Thomas Christy, a Computer Science PhD student at Bangor University is hoping to bring this reality a little nearer by developing a system that will enable computers to read and interpret our emotions and moods in real time.*

*Tom's work focuses on 'hands-on' pattern recognition and machine learning. His supervisor is a world expert in pattern recognition and classification, specifically in classifier ensembles. A classifier ensemble is a group of programmes that independently analyse data, and decide to which label or group the data belongs. The final decision is reached by a 'majority' or consensus, and is often more accurate than individual classifier decisions.*

*The plan is to combine brainwave information collected from a single electrode that sits on the forehead as part of a 'headset', a skin conductance response (which will detect tiny changes in perspiration as first indicators of stress) and a pulse signal, reflecting the wearer's heart rate. This information will form the data fed into a classifier ensemble set to determine a person's emotion.*

*Tom is aiming to pioneer classification software techniques that will allow players' emotions to be identified within the gaming environment. This will open up new and exciting markets for the gaming industry. New games can be created; where players must control their feelings in order to advance within their virtual environment.*

*There are many other possible applications for this type of technology; for example, to determine customer preferences and brand effectiveness, monitoring anxiety levels of soldiers during military training, and providing instant neuro-feedback to combat addictive behaviours.*

# NEW, IMPROVED THEREMIN

***This design is an upgrade of our most popular Theremin, which was featured in the May/June 2008 issue. We have added a voicing control, incorporated a larger loudspeaker and increased the power output. We've also changed the power supply to avoid problems with switchmode DC plugpacks.***

**By JOHN CLARKE**

JUST in case you are not familiar with the Theremin, here is a brief rundown on this most unusual device. It is an electronic musical instrument that can be altered in pitch and volume using proximity effects.

To play the instrument, the right-hand is moved horizontally toward the antenna to increase the pitch and away from the antenna to reduce the pitch. Left-hand movements over the horizontal plate provide volume control. The volume is reduced as you move your hand closer to the plate.

In operation, the pitch change afforded by the antenna is infinitely variable over several octaves. In some ways, this is similar to playing a trombone, whereby the slide is moved back and forth to vary the pitch. Although most people can play the instrument at first attempt, an ear for pitch and fine hand control are essential requirements to become proficient at playing the Theremin.

Several fine performances by Peter Pringle using a Theremin are presented at **www.peterpringle.com/thereminmp3s.html**. These demonstrate only a fraction of what can be accomplished with a Theremin in the hands of a skilled musician. The same website has links to *YouTube* performances, some of which are quite remarkable.

## Electronic music

The fascination with the instrument, when it was first invented by Leon Theremin in 1919, was that it represented a revolutionary change in thinking about how music could be produced. It challenged traditional stringed, brass and percussion musical instruments. Its design eventually led to the development of the Moog Synthesiser and electronically synthesised music in general. Even today, that fascination with producing sounds electronically is still prevalent. If you are interested in the history of the Theremin there is more information in the section headed 'Theremin Origins'.

The Theremin invention was not only 'instrumental' in the development of electronic music; it also had an impact on a free-form style of playing music. The free-gesture hand control afforded by the Theremin was the harbinger of the modern Sensor Chair synthesiser controller, where the whole body becomes a part of the musical generation process.

Before this, Jimi Hendrix was creating new sounds by generating feedback between his guitar and the amplified sound and then moving his body to modulate the amplitude. It freed him from the restriction of generating music solely by plucking the guitar strings.

In recent times there has been quite a renewal of interest in the Theremin, and there is a lot of information on the Internet. However, none of it is really helpful if you want to build your own Theremin.

This is where the Theremin project described here comes into the picture. It uses just three low-cost ICs and a handful of other components. Our Theremin is considerably smaller than the original design too, although you could build it into a larger timber box if you prefer.

As noted above, this design is an upgraded

**Specifications**

| | |
|---|---|
| Power requirements | 12VAC at 250mA minimum or 12V DC at 250mA |
| Current draw: | 30mA with no sound from loudspeaker, up to 200mA at full volume. |
| Output frequency range | Greater than five octaves, from 50Hz to >2kHz |
| Volume control range | >60dB |
| Audio output level | 600mV RMS |

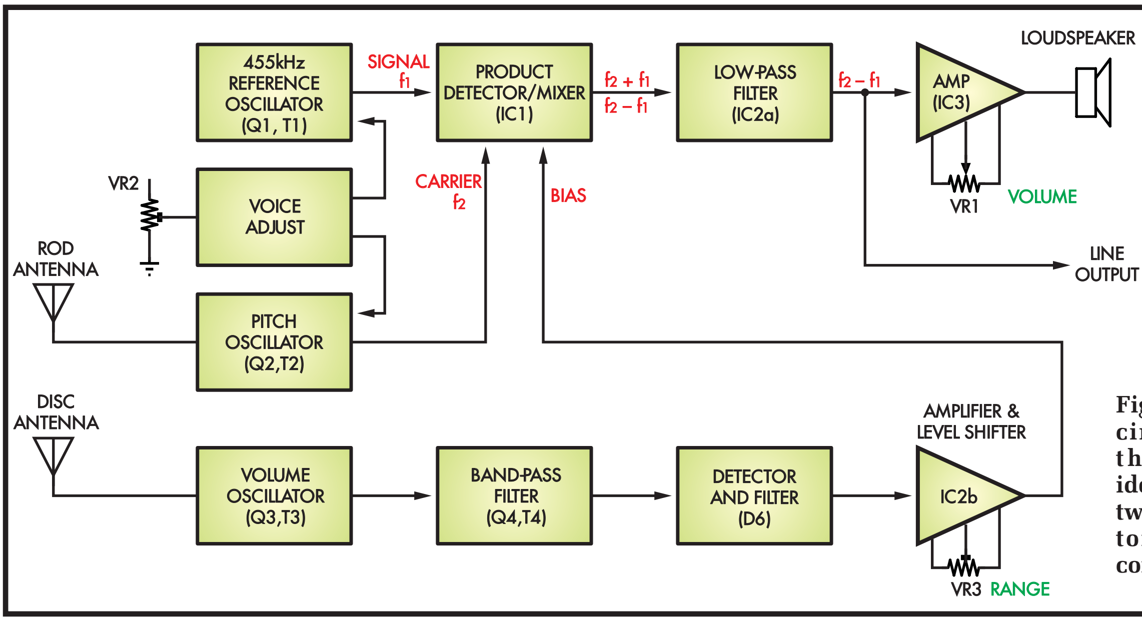



**Fig.1: the Theremin circuit comprises three virtually identical oscillators, two to generate the tone and one to control the volume.**

version of our very popular Theremin that was published in May/June 2008. Interest in that project far exceeded expectations and kits are still being built around the world in large numbers. Compared to the old design, this latest Theremin is easy to construct, with minimal wiring, and it also includes a larger internal loudspeaker.

It is built into a medium-sized plastic box, with the antenna and volume plate mounted at opposite ends. The internal loudspeaker is for practice sessions and a line output is included for connection to a sound system. The only manual controls are an on/off switch and volume control for the loudspeaker. A 12V AC adaptor powers the Theremin.

The original Theremin was designed to run from a 9V DC plugpack. However, DC plugpacks now being sold are mostly switchmode types and these do not work well with a Theremin. They can produce extraneous pitch changes, because a Theremin relies on very small capacitance changes with respect to earth (ground) to alter the pitch of the tone.

Switchmode plugpacks effectively ground capacitance either at the switching rate and/or the mains frequency (50 or 60Hz). This will cause a Theremin to misbehave unless the power supply earth is fully grounded.

The way around this dilemma is to change the supply to use a plugpack with an AC output. In this case, there is no internal switchmode circuitry and therefore no extraneous pitch changes.

## Voicing

The original design produced a fairly pure sinewave tone that was not fully characteristic of a Theremin, which should have a richer harmonic content. Hence, the new design includes a voicing control. This varies the tone from a pure sinewave to something akin to a cello sound at low frequencies, extending to soprano voice at the higher frequencies.

Below and on the facing page, we have included a number of screenshots from Nero Wave Editor (see separate panel to see how we did it) to show the typical waveforms available from our new design.

## How it works

The block diagram of Fig.1 shows the basic arrangement of the Theremin circuit. It comprises three oscillators that all operate at about 455kHz. A beat signal is generated by mixing the reference and pitch oscillators together to produce an audible tone. The volume oscillator is then used to change the level of the tone output.

The reference oscillator operates at a fixed frequency and is mixed with the pitch oscillator in the product detector (IC1). The pitch oscillator changes in frequency depending upon the amount of capacitance to earth presented by your hand near the antenna.

The product detector essentially mixes the reference oscillator ($f_1$) with the pitch oscillator ($f_2$) to produce sum ($f_1 + f_2$) and difference ($f_2 – f_1$) frequencies.

The sum ($f_1 + f_2$) signal is around 900kHz and is removed with a low-pass filter. After filtering, we are left with the difference signal of $f_2 – f_1$. This normally comprises audio frequencies from 2kHz down to below 10Hz.

**This shows the Theremin output at 100Hz with the minimum setting for the voice. The sound is relatively pure and similar to the original Theremin**

**Now the same 100Hz frequency, but with the voicing adjusted to maximum. The sound produced by this waveform is reminiscent of a cello**

So, if the pitch oscillator frequency is 456kHz and the reference oscillator is at 455kHz, we will obtain a 1kHz audio output from the low-pass filter. If both the pitch and the reference oscillators are at the same frequency, then there will be no audio output.

Varying the coupling between the pitch and reference oscillators provides for voicing. When the pitch oscillator frequency differs from the reference oscillator we obtain an output tone, and the difference in frequency between the two oscillators tends to 'pull' or distort the $f_2 - f_1$ wave shape so that it is not a sinewave. Potentiometer VR2 allows adjustment of the coupling and its consequent waveform distortion or voicing.

Audio output from the low-pass filter is applied to a power amplifier to drive a loudspeaker. The overall volume from the amplifier is set by the volume control VR1.

The sensor plate or disc controls the volume oscillator. As you bring your hand closer to the loop, the frequency of the volume oscillator decreases. This is fed to a bandpass filter that has a centre frequency ($f_C$) that is higher than the volume oscillator frequency.

As the frequency of the volume oscillator increases, the level from the bandpass filter will also increase as it approaches the centre frequency. Similarly, as the frequency of the volume oscillator decreases, the level from the bandpass filter will also decrease. Fig.2 shows the output of the bandpass filter in response to the change in volume oscillator frequency.

This signal level is detected using a diode and filtered to produce a DC voltage. Amplifier IC2b increases the DC voltage and the level shifter sets the voltage so that it can control the product detector output level over a suitable range via its bias input. Changing the biasing of IC1 alters the gain of this product detector.

## Circuit details

The full circuit diagram of the Theremin is shown in Fig.3. It comprises three JFETs (junction field-effect transistors), four pre-wound IF (intermediate frequency) transformers, three ICs, several diodes, a 3-terminal 9V regulator and associated resistors and capacitors.

All three oscillators are essentially identical. Each oscillator comprises a JFET and a standard IF transformer. These IF transformers are commonly used in low-cost AM radio receivers. Each IF transformer comprises a tapped main winding and a parallel-connected capacitor to form a tuned circuit. The secondary winding couples the oscillator signal to the following circuitry.

Each JFET drives a portion of the primary winding (ie, between the tapped connection at pin 2 and ground) while the signal across the full winding is applied back to the gate via a 68pF capacitor. This provides positive feedback to ensure oscillation.

To make them controllable by hand capacitance, the pitch and volume oscillators have the pitch antenna and volume disc attached to the top (ie, active end) of the tuned coils, where they will have the most effect.

## Diode coupling

Diode D5 connects the signal from pin 2 of transformer T1 (reference oscillator) to pin 2 of transformer T2 (pitch oscillator) via 10nF capacitors. The diode is used as part of a capacitive divider with the 10nF capacitors, whereby its junction capacitance varies with the applied reverse voltage across it. This reverse voltage is provided by trimpot VR2 and can be adjusted between 0 and 9V. The diode anode (A) connects to ground (0V) via a 100kΩ resistor, while the cathode (K) connects to the wiper of VR2 via another 100kΩ resistor.

With VR2 wound fully up to the 0V supply, there is no reverse voltage across D2 and this provides the maximum capacitance across the diode and therefore maximum coupling between the two oscillators.

When VR2 is wound fully toward the positive 9V supply, the diode is reverse biased and provides minimal capacitance. Maximum capacitance of the diode is very small, at around 4pF, but this is sufficient to produce the coupling action required.

The reference oscillator is applied to the signal input (pin 1) of an MC1496 balanced mixer, IC1. The pitch oscillator

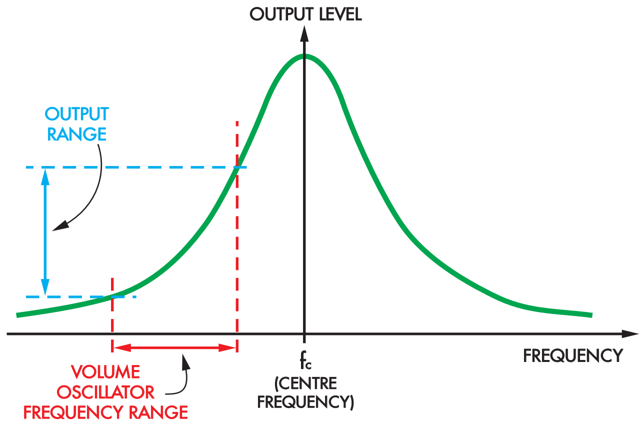
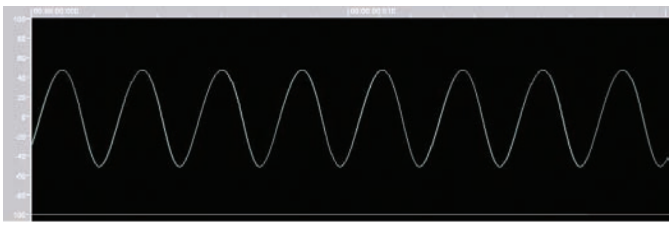
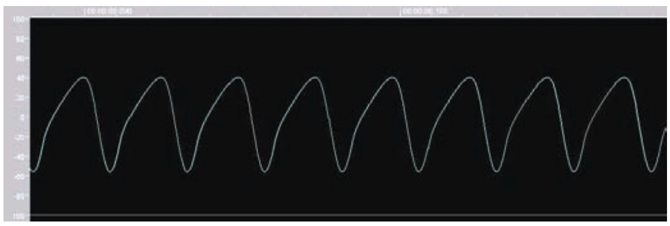


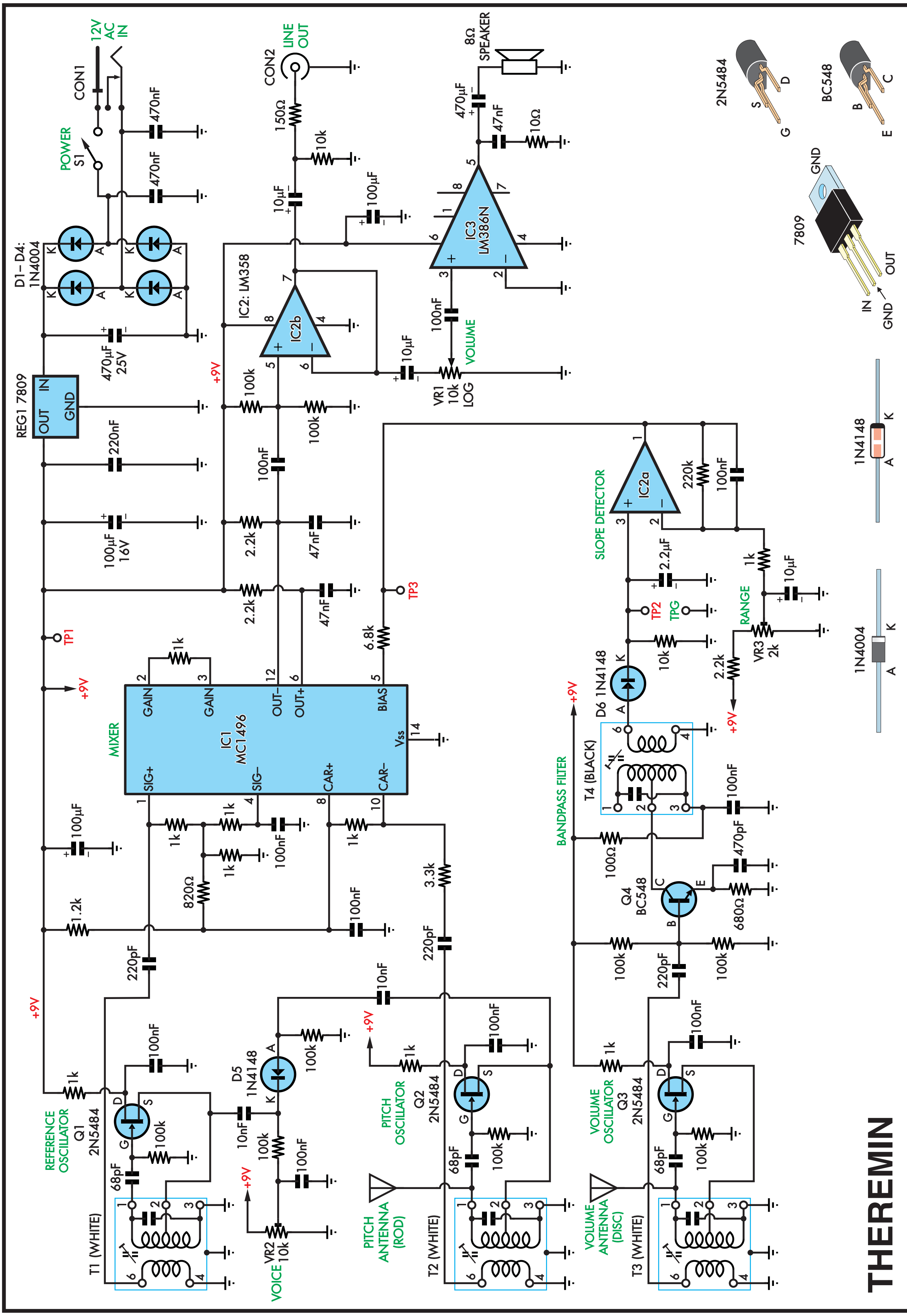

**Fig.2: the output of the bandpass filter in response to the change in volume oscillator frequency. As the frequency of the volume oscillator increases, the level from the bandpass filter will also increase as it approaches the centre frequency of the filter. Similarly, as the frequency of the volume oscillator decreases, the level from the bandpass filter will also decrease**



**At 400Hz, the above waveform with minimum setting for the voicing has a near sinusoidal shape and sounds 'pure' in tone**



**While at the maximum voicing setting for 400Hz, the waveform is not so pure and has the tonal characteristic of a soprano voice**




# THEREMIN

Fig.3: a few subtle but very important changes have been made to the original Theremin circuit. These are explained in the text.

signal is attenuated using a 3.3kΩ resistor and the 1kΩ resistor before being applied to the carrier input at pin 10. This reduction in signal level is to prevent overloading the mixer stages of IC1. Resistors between the +9V supply and ground set the bias voltages for the inputs of the balanced mixer, while the 1kΩ resistor between pins 2 and 3 sets the gain of the circuit.

IC1 provides a balanced output with signals at pin 6 and pin 12. These complementary outputs are filtered with a 2.2kΩ pull-up resistor and a 47nF capacitor to produce a roll off above about 1.5kHz. This roll off heavily attenuates frequencies at 455kHz.

The output from pin 12 is AC-coupled to op amp IC2b. IC2b is biased at half-supply using the two 100kΩ voltage divider resistors across the 9V supply.

This biasing allows the op amp to produce an output of 600mV (~850mV peak) above and below 4.5V without clipping. IC2b's output signal also goes to the line output terminal.

IC3 is an LM386 1W amplifier that drives the loudspeaker via a 470µF electrolytic capacitor. The 47nF capacitor and series 10Ω resistor form a Zobel network to prevent spurious oscillation from the amplifier.

## Volume oscillator

Output from the volume oscillator at the secondary winding of T3 (pin 6) is AC-coupled to the base (B) of transistor Q4. This is connected as a common-emitter amplifier, with the collector load being a parallel-tuned circuit comprising an IF coil with internal capacitor.

Transformer T4 and the associated capacitor are tuned to a frequency just above the maximum available from the volume oscillator. The emitter resistor is bypassed with a 470pF capacitor to provide a roll off below about 500kHz.

The output level from T4 will vary in proportion to the frequency from the volume oscillator. This is because the filter provides a sharp roll off below its tuning frequency, and small changes in frequency below the centre frequency will cause large changes in the filter response. The action of this circuit is a simple frequency modulation (FM) detector.

The high frequency signal from T4 is rectified by diode D6 and filtered to provide a DC signal, which is amplified by op amp IC2a.

Amplification can be up to about 220 times with trimpot VR3 set at 0Ω. Typically, the gain is about 100, since VR3 is set so that IC2a's output sits at about 7V with the hand away from the volume plate or disc. IC2a's output is then fed, via a 6.8kΩ current-limiting resistor, to the bias input of IC1 at pin 5 to vary the level of the audio signal.

## Power supply

As mentioned earlier, power for the circuit comes from an AC plugpack. Alternatively, the Theremin could be powered from a 12V battery or an earthed DC power supply. As already noted, a 12V DC switchmode plugpack supply is not suitable. Most 'plugpack'-type supplies sold these days are switchmode types, so be careful with this one!

Switch S1 applies power to the circuit. The 470nF capacitors on each side of the input supply ground the AC connections to swamp any capacitance effects of the plugpack to ground. This ensures there are no spurious sounds from the Theremin due to the plugpack.

### Theremin Origins

**In 1919, a Russian physicist named Lev Termen (or Leon Theremin as he is called in the West) invented an electronic musical instrument called the 'Theremin'. At that time, the Theremin was innovative and unique in the musical world, and was essentially the first electronic instrument of its kind. Playing it relied solely on hand movements in the vicinity of two antennas to control two electronic oscillators – one antenna to vary the *pitch* of the sound and the other to change the *volume*.**

**In operation, the pitch change afforded by the antenna is infinitely adjustable over several octaves, with the frequency increasing as the hand is brought closer to the antenna. An ear for pitch and fine hand control are essential requirements to become proficient at playing the Theremin.**

**To a large extent, the Theremin was made famous by recitalist Clara Rockmore. Born in Lithuania in 1911, she was an accomplished violinist by the age of five. She began to learn to play the Theremin after meeting Leon Theremin in 1927, and developed a unique technique for playing the instrument. This involved minute finger movements to capture and modulate the tone of the note and enabled her to play the instrument with great precision.**

**The Theremin was subsequently further developed and manufactured by the Radio Corporation of America (RCA) around 1929. This design consisted of a large box with an attached antenna and wire loop. The antenna provided the control for the pitch, while the loop enabled the volume to be adjusted.**

**In practice, the pitch control antenna was mounted vertically while the volume loop sat horizontally, to minimise interaction between them. Of course, the circuit used valves.**

**General Electric (GE) and Westinghouse also made Theremins in the 1920s. However, the number of units produced was quite modest, with only about 500 being made.**

**Today, the Theremin is hailed as the forerunner of modern synthesised music and was instrumental in the development of the famous Moog synthesisers. Because of its unique sound, it has been popular with music producers for both film and live performances. The sound is ideal for background setting the scene for supernatural events and for close encounters with extraterrestrial beings in science fiction movies.**

**Famously, a Theremin was used to produce background music in the feature film *The Ten Commandments* by Cecil B de Mille. Its eerie sounds have also made it ideal for science fiction movies, including the 1951 and the 2008 versions of *The Day the Earth Stood Still* and *It Came From Outer Space*, and in thriller movies such as *Spellbound* and *Lost Weekend*.**

**In addition, Bands such as the Bonzo Dog Band and Led Zeppelin have embraced the Theremin. The Beach Boys used an instrument similar to the Theremin – called an Electro-Theremin (also named a Tannerin) – in their famous *Good Vibrations* hit from the 1960s. The Electro-Theremin differs from the Theremin in that it incorporates a mechanical controller to adjust the pitch rather than hand movements relative to an antenna. The sound, however, is very similar to the Theremin.**

**Many commercial Theremins are available on the market today, including the Etherwave series from Moog Music Inc, PaiA's Theremax and Wavefront's Classic and Travel-Case Theremins.**

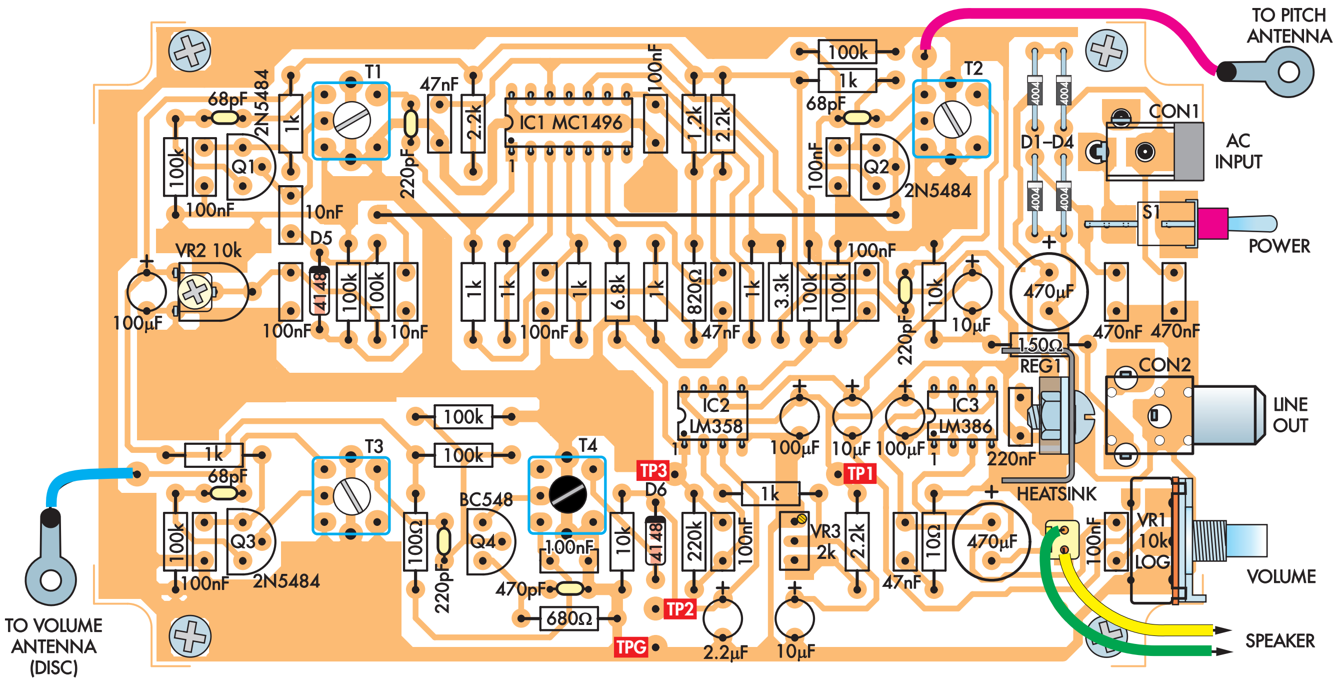
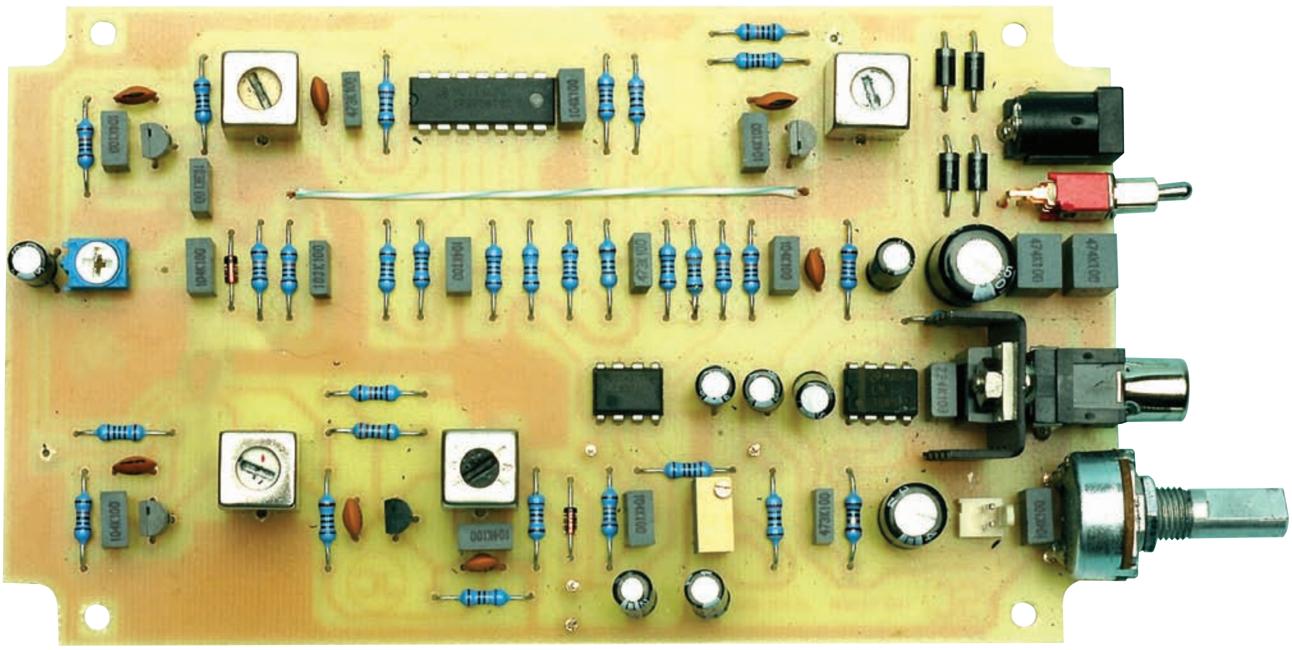



**Fig.4 (above): everything except the speaker, volume plate and pitch antenna mount on a single PC board, so construction and wiring should be quite easy. Note the differences in the transformers: three have white cores while one has a black core. This is very easy to see in the matching photo below – so don't mix them up!**



Diodes D1 to D4 rectify the 12V AC voltage and this is then filtered with a 470µF capacitor to provide a relatively smooth 16V DC supply for REG1, which is a 7809 3-terminal regulator that delivers 9V to the circuit. A 220µF capacitor close to the regulator output ensures stability and several 100µF capacitors decouple the supply at positions further away on the PC board.

## Construction

Most of the parts for the Theremin are assembled onto a PC board, coded 795 and measures just 147mm × 85mm. This board is available from the *EPE PCB Service*. The circuit board is housed in a plastic utility box measuring 158mm × 95mm × 53mm.

While our assembly description revolves around the plastic case with its small speaker, there is no reason why you couldn't build it into a much larger case in keeping with a traditional musical instrument. An external power amplifier and loudspeaker would also make a considerable improvement to the overall sound quality.

Indeed, fitting it into a large box may also improve the operation – the 'playability' if you like – of the Theremin. Separating the pitch (antenna) and volume (plate) controls may give you more control over both. Note that we haven't tried this idea out, but there is nothing to stop you doing it if you want.

You can begin construction by checking the PC board for any defects such as shorts between tracks, breaks in

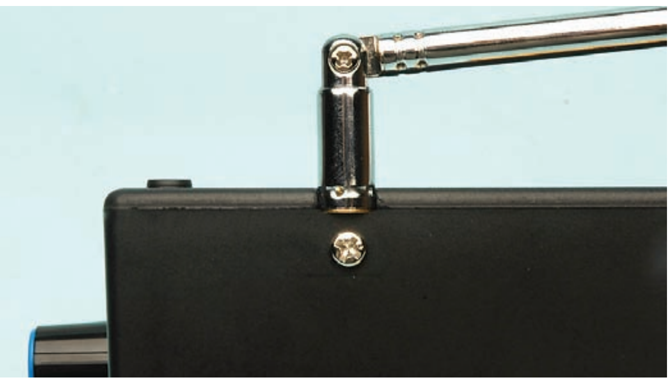
**The control end of the Theremin – from left to right, the volume control, line output socket, power switch and 12V AC power input.**

the copper tracks and incorrectly drilled holes. Check the hole sizes for the IF transformers (T1 to T4), the PC mount components, including the power socket, the phono socket and potentiometer VR1. Four corner mounting holes should be drilled to 3mm. Holes for the PC stakes should be sized to suit their diameter; they should be a tight fit.

Check that the PC board fits into the plastic case and that it has clearance for the corner pillars. The PC board should have its corners shaped to provide this clearance. If this has not been done, a rat-tail file can be used to shape each corner to the outline shown on the PC board pattern. Before proceeding further, mark out the hole positions for the four corner mounting points for the PC board on the base of the case, and drill these out to 3mm.

The component overlay for the PC board and the wiring details are shown in Fig.4. The long link on the PC board is made using an 80mm length of hookup wire. It is cut and the end stripped so that it is held straight between the two PC pads on the PC board. You can now insert the resistors. Use the resistor table as a guide to selecting each value. In addition, use a digital multimeter to check each resistor value before it is soldered in.

The three ICs can be mounted next, taking care with their orientation. Make sure that IC2 and IC3 are placed



**Here's how the pitch antenna mounts: a small cutout in the case lid allows it to be mounted to the side of the case via the screw clearly visible in this photo.**

## Parts List – Theremin

1 PC board, code 795, available from the *EPE PCB Service*, size 147mm × 85mm
1 plastic utility box, 158mm × 95mm × 53mm
1 front panel label, 155mm × 92mm
1 12V AC 500mA plugpack (**do not use a switch-mode 12V DC plugpack**)
1 telescopic antenna, 6.5mm largest diameter (875mm fully extended) (pitch antenna)
1 80 × 95mm aluminium plate, 1mm thick (for volume)
1 PC-mount DC socket (2.5mm diameter pin)
1 panel-mount phono socket
1 SPDT miniature PC-mount toggle switch (S1)
1 75mm 8Ω loudspeaker
3 2nd IF coils (white) (T1 to T3)
1 3rd IF coil (black) (T4)
1 mini TO-220 heatsink, 19 × 19 × 9.5mm
1 knob to suit potentiometer, with 2 nuts
2 solder lug eyelets
1 2-way pin header plug and socket
12 M3 × 10mm screws
3 M3 nuts
4 9mm tapped nylon standoffs
4 stick-on rubber feet
1 260mm length of medium-duty hookup wire
1 80mm length of light duty hookup wire (wire link)
1 100mm cable tie
7 PC stakes

**Semiconductors**
1 MC1496P balanced modulator (IC1)
1 LM358 dual op amp (IC2)
1 LM386N-1 1W audio amplifier (IC3)
1 7809 3-terminal regulator (REG1)
3 2N5484 or 2N5485 *N*-channel JFETs (Q1-Q3)
1 BC548 *NPN* transistor (Q4)
4 1N4004 1A diodes (D1 to D4)
2 1N4148 signal diodes (D5,D6)

**Capacitors**
1 470µF 25V PC electrolytic
1 470µF 16V PC electrolytic
3 100µF 16V PC electrolytic
3 10µF 16V PC electrolytic
1 2.2µF 16V PC electrolytic
2 470nF MKT polyester
1 220nF MKT polyester
8 100nF MKT polyester
3 47nF MKT polyester
2 10nF MKT polyester
1 470pF ceramic
3 220pF ceramic
3 68pF ceramic

**Resistors (0.25W, 1%)**

| | | | | |
|---|---|---|---|---|
| 1 330kΩ | 1 220kΩ | 8 100kΩ | 2 10kΩ | 1 6.8kΩ |
| 1 3.3kΩ | 3 2.2kΩ | 1 1.2kΩ | 9 1kΩ | 1 820Ω |
| 1 680Ω | 1 150Ω | 1 100Ω | 1 10Ω | |

1 10kΩ log 16mm potentiometer (VR1)
1 10kΩ horizontal trimpot (VR2)
1 2kΩ multiturn, top adjust trimpot (VR3)

## Resistor Colour Codes

| | No. | Value | 4-Band Code (1%) | 5-Band Code (1%) |
|---|---|---|---|---|
| ❏ | 1 | 330kΩ | orange orange yellow brown | orange orange black orange brown |
| ❏ | 1 | 220kΩ | red red yellow brown | red red black orange brown |
| ❏ | 8 | 100kΩ | brown black yellow brown | brown black black orange brown |
| ❏ | 2 | 10kΩ | brown black orange brown | brown black black red brown |
| ❏ | 1 | 6.8kΩ | blue grey red brown | blue grey black brown brown |
| ❏ | 1 | 3.3kΩ | orange orange red brown | orange orange black brown brown |
| ❏ | 3 | 2.2kΩ | red red red brown | red red black brown brown |
| ❏ | 1 | 1.2kΩ | brown red red brown | brown red black brown brown |
| ❏ | 9 | 1kΩ | brown black red brown | brown black black brown brown |
| ❏ | 1 | 820Ω | grey red brown brown | grey red black black brown |
| ❏ | 1 | 680Ω | blue grey brown brown | blue grey black black brown |
| ❏ | 1 | 150Ω | brown green brown brown | brown green black black brown |
| ❏ | 1 | 100Ω | brown black brown brown | brown black black black brown |
| ❏ | 1 | 10Ω | brown black black brown | brown black black gold brown |

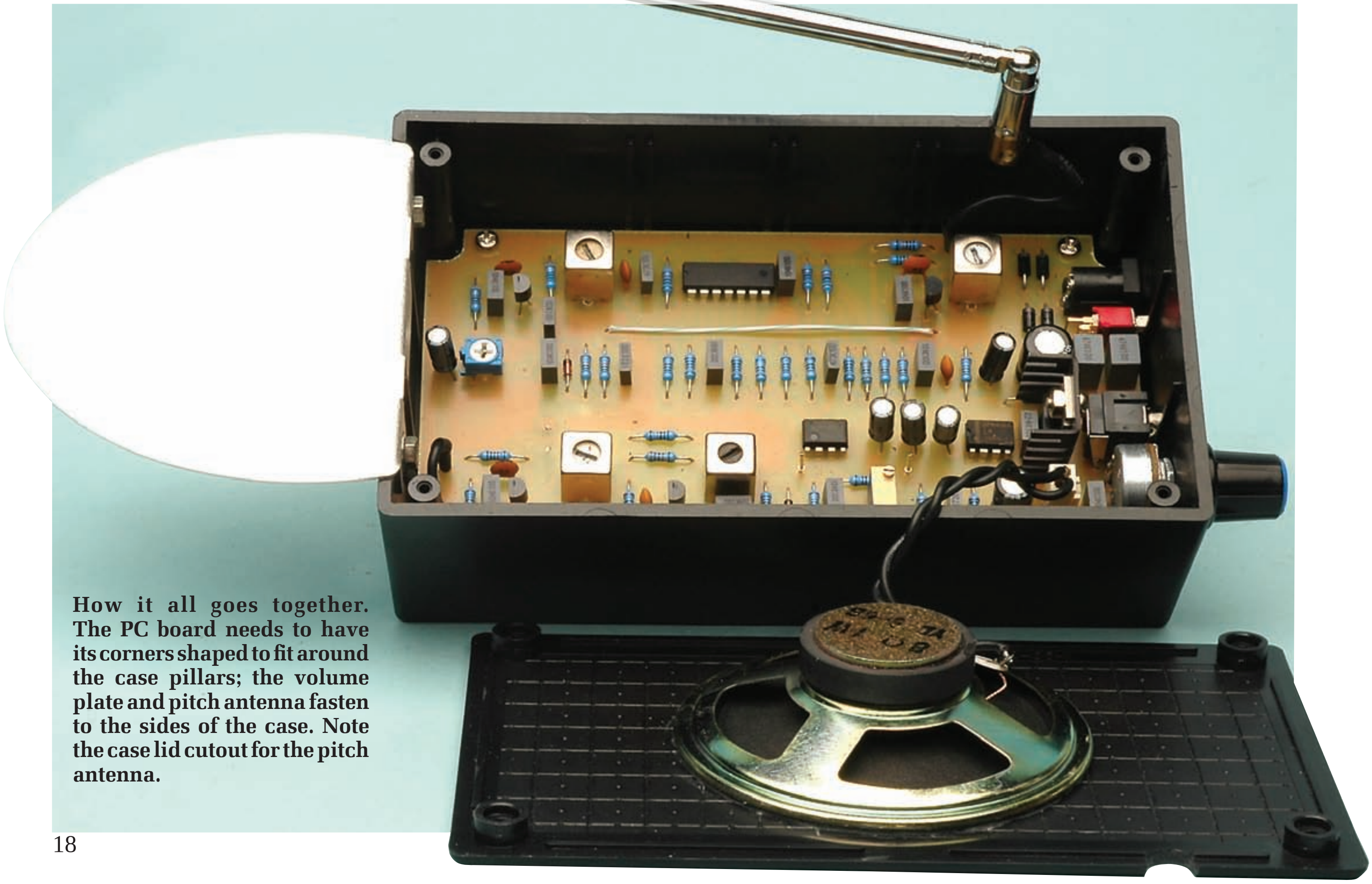
in their correct positions. Next, the capacitors can be mounted, noting that the electrolytic types are polarised and must be oriented with the correct polarity, as shown in Fig.4. The MKT and ceramic types are coded and you can cross-check these codes against the values shown in the table opposite.

PC stakes are used for the antenna and volume disc connections, for the test points TP1 to TP3 and TP GND and for securing VR1 to the PC board. These can be inserted and soldered in now. In addition, the 2-way pin header for the loudspeaker connection can be inserted now.

### Transformer mounting

Transformers T1 to T4 are mounted as shown in Fig.4 and photos. Be sure to place the ones with the white slugs (the threaded ferrite core) in the T1 to T3 positions, and the coil with the black slug in the T4 position.

Now mount JFETs Q1-Q3 (2N5484), transistor Q4 (BC548) and the 7809 3-terminal regulator, REG1. The 1N4004 diodes D1 to D4 and the 1N4148 types for D5 and D6 can be mounted next, taking care with their orientation. REG1 can be installed after the heatsink is attached to the metal tab, using an M3 × 10mm screw and nut.



**How it all goes together. The PC board needs to have its corners shaped to fit around the case pillars; the volume plate and pitch antenna fasten to the sides of the case. Note the case lid cutout for the pitch antenna.**

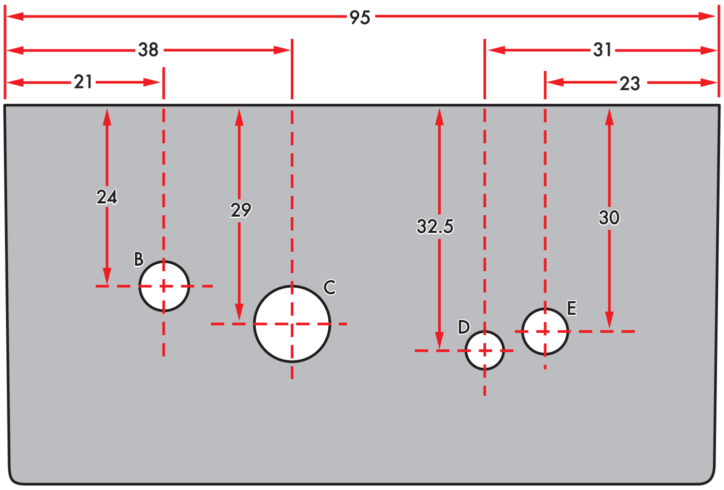



**Fig.5: the 'Controls' end of the box showing the cutouts required. Hole B is for the volume pot, C the line out, D is for the power switch and E is for the 12V AC power in.**

Trimpots VR2 and VR3 can be mounted now. Potentiometer VRl may require the shaft to be cut to length to suit the knob. The potentiometer is mounted in position as shown in Fig.4, and is supported using two PC stakes just behind the potentiometer body.

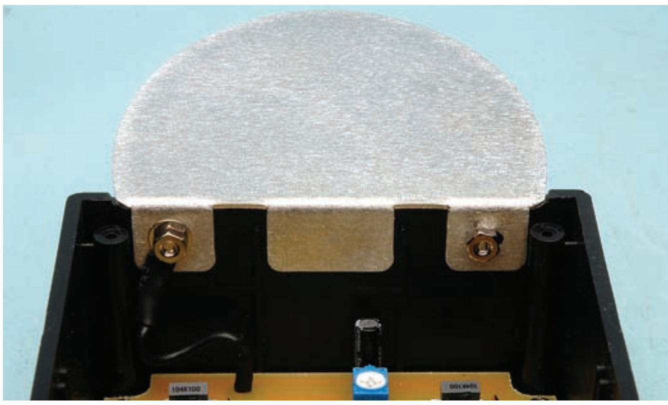
Scrape or file off the passivated coating on the potentiometer body just at the positions where the PC stakes make contact. This will allow the PC stakes to be soldered to the potentiometer body. The soldering holds the potentiometer secure and the lower PC stake earths the potentiometer body to the circuit ground. Attach a nut to the pot-securing thread. This is used as a spacer between the box and pot.

Next, the power socket, switch (S1) and the phono socket can be inserted and soldered in place.

With the PC board complete, you are ready to work on the case. You will need to drill holes in the sides of the box for the DC panel socket, the phono socket and for the antenna-securing screw.

## Volume plate

The volume plate is made from 1mm gauge aluminium, shaped as shown in Fig.6. One end is bent over at right angles so it can be secured to the side of the box using M3 screws and nuts. Mark out and drill the holes required in the side of the box. The aluminium disc is connected via a lead and solder lug to the PC board.



**Looking inside the open case, this photo shows how the volume plate is secured.**

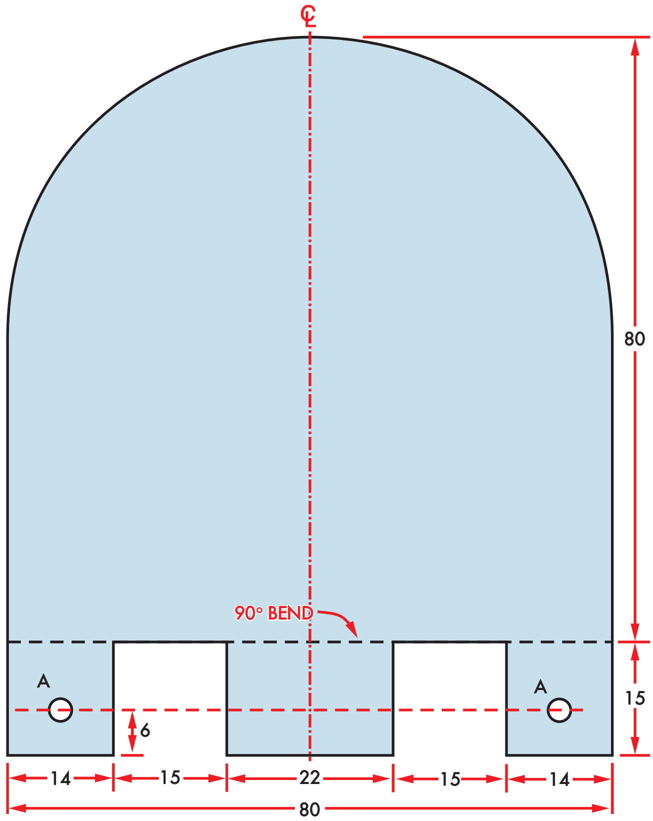



**Fig.6: the 1mm-thick aluminium volume plate. Both these diagrams are reproduced same size.**

The antenna is attached to the side of the case with a 10mm-long M3 screw that screws into the tapped base of the antenna. Mark and drill the hole in the side of the box. An eyelet is clamped between the box and antenna to make the wire connection to the PC board. Note that the lid of the box will require a half-circle cutout to accommodate the antenna.

Mark and drill out the holes in the end of the box for the potentiometer, phono socket, power switch and power socket, as shown in Fig.5. Mount the PC board onto four 9mm tapped spacers using four 10mm M3 screws. Slide the PC board into the box so that the PC-mount components enter the holes and then push the opposite edge of the PC board down into the box.

### Capacitor Codes

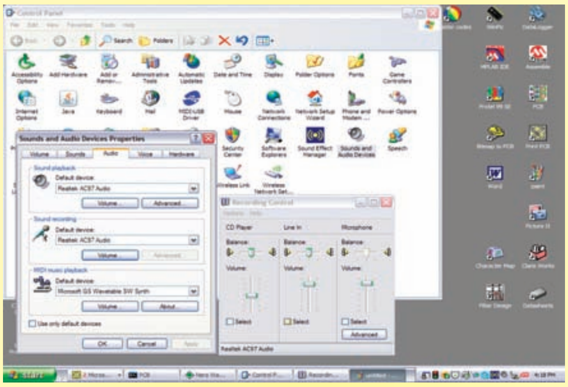
| Value | µF value | IEC Code | EIA Code |
|---|---|---|---|
| 470nF | 0.47µF | 470n | 474 |
| 220nF | 0.22µF | 220n | 224 |
| 100nF | 0.1µF | 100n | 104 |
| 47nF | 0.047µF | 47n | 473 |
| 10nF | 0.01µF | 10n | 103 |
| 470pF | NA | 470p | 471 |
| 220pF | NA | 220p | 221 |
| 68pF | NA | 68p | 68 |

## Displaying the Theremin waveforms

The waveforms on pages 12 and 13 were recorded using Nero Wave Editor. Similar waveforms can be displayed using the NCH Wavepad or Audacity software, or similar.

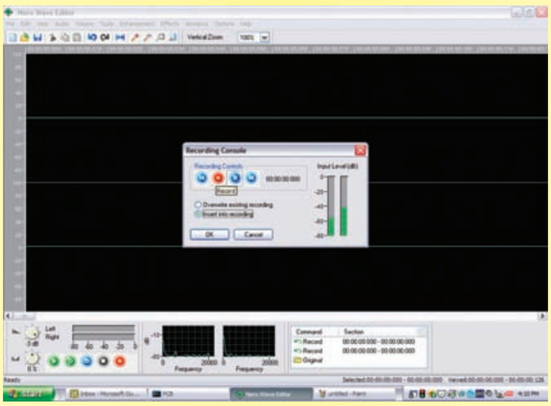
The signal from the Theremin was connected to the line input of the computer. An adaptor lead (phono plug to 3.5mm stereo jack) is required to connect the Theremin output to the computer input. The recording will be in either the left or right channel as the single phono output will only connect to one channel or the other.

In Windows XP, the signal levels are set to prevent clipping of the signal, by selecting <Control Panel>, <Sounds and Audio Devices Properties>, <Sound Recording Volume> and then adjusting the Line In slider.

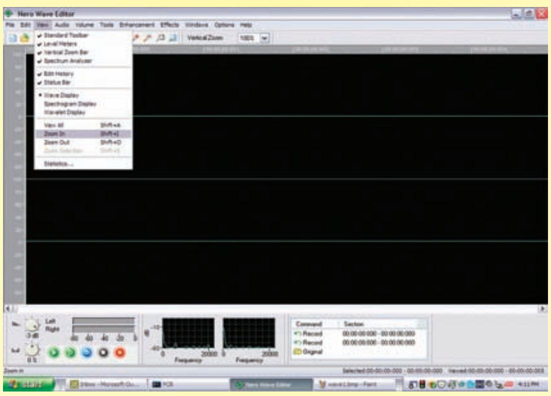


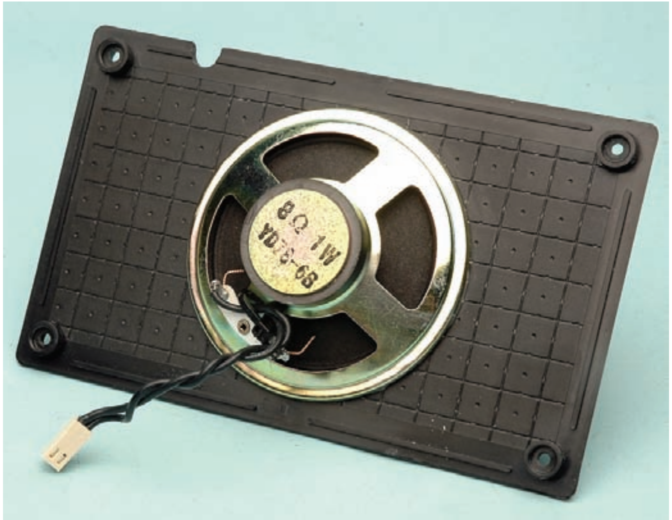
The level meter on the Nero Wave Editor Recording Console shows the signal reading; the volume is set for signal level below the 0dB maximum.

The signal is then recorded using a 16-bit 44.1kHz sample rate.



The recorded signal can then be expanded out to see the waveform in detail using the zoom in feature.





**The internal speaker is secured to the lid with silicone sealant or other suitable adhesive.**

Secure the PC board to the box with four M3 × 10mm screws into the 9mm standoffs from beneath the box. Attach the four rubber stick-on feet.

Attach the volume disc to the end of the case using two M3 × 10mm screws and nuts and with the eyelet for the volume disc wire clamped under a nut.

The loudspeaker is centrally mounted on the lid, which has a pattern of holes to let the sound out. We used 9 x 6.35mm holes, with one in the centre and eight spaced evenly on a 16mm radius. The loudspeaker is attached to the lid of the case using contact or other suitable adhesive. Before affixing it, make sure that when the lid is placed in position, the speaker terminals face towards the 2-way connector on the PC board.

The loudspeaker is wired to the 2-way header socket on the PC board using two 70mm lengths of hookup wire. A cable tie wrapped around the wire and under the steel speaker frame at the loudspeaker connector will help prevent the wires breaking away from the connector.

### Setting up

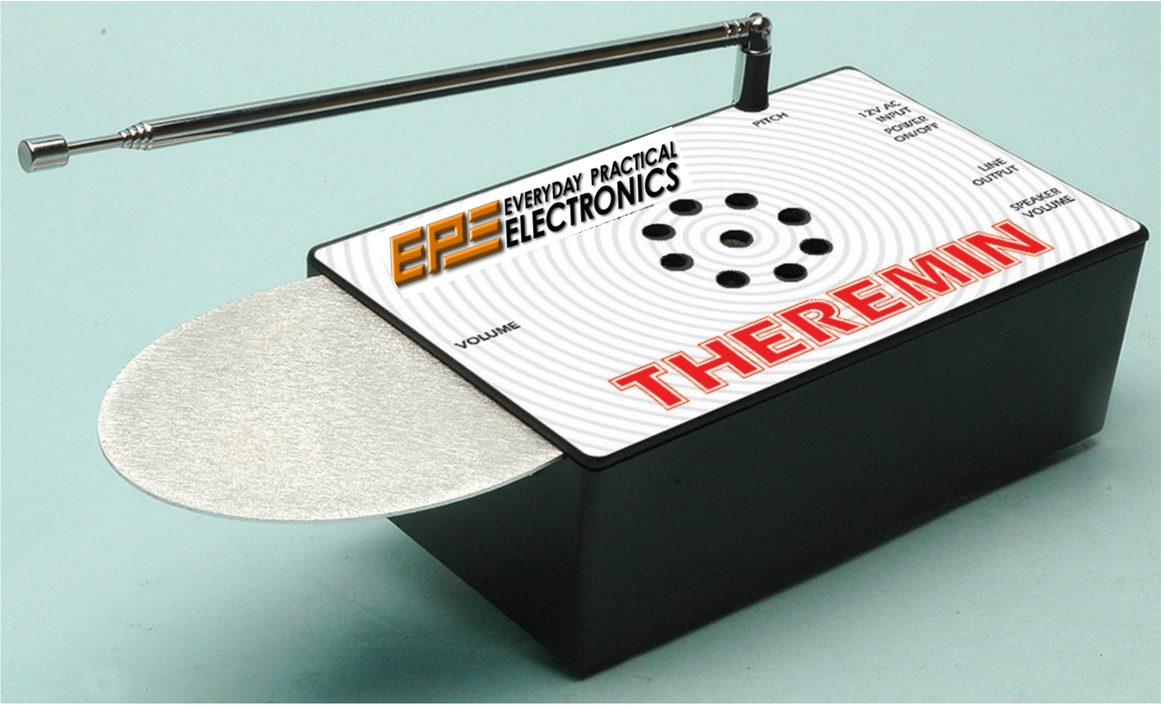
When your Theremin is complete, check your work carefully. Apply power and confirm that there is 9V between TP1 and TP GND (the voltage could range from between 8.75V and 9.25V).

Using a suitable alignment tool, wind the ferrite slug for T2 clockwise until there is resistance to movement (*do not* force it). Then count the number of turns to wind it out anticlockwise completely. Set the slug half way between the two extremes.

### Volume alignment

You must carry out the volume and pitch adjustments away from the effects of metallic objects, otherwise the Theremin will require retuning when removed from these grounding sources.

Wind the slug for T3 fully anticlockwise and then out again, counting the number of turns. That done, set T3 about 30% of turns anticlockwise. This will set the frequency of the volume oscillator (T3) to below the frequency of the pitch oscillator (T2) to prevent extraneous sounds that can be emitted if the two oscillators are close in frequency.




**This photo of the completed Theremin clearly shows the volume control 'plate' on the left side. The pitch antenna at the back (which is actually a telescopic whip antenna) is in this case folded down 90° and almost fully contracted. You can also see the holes drilled in the case top and panel for the sound to get out.**

Now adjust T4's slug (with your hand and any multimeter wires away from the volume disc) so that there is 2.5V between 'test points' TP GND and TP2. Move your hand close to the volume disc and the voltage should drop in value. If the voltage goes up, readjust T4's slug anticlockwise with your hand away from the disc. Adjust it until the voltage increases and then drops back to 2.5V. Measure the voltage between TP3 and TP GND and set VR3 so that there is 7V, with your hand away from the volume disc.

Check that the voltage falls to 0V for a reasonable range of hand movement over the plate. You can change the range of volume control by adjusting the setting of the slug in T4.

Setting transformer T4 so there is more than 2.5V at TP2, with your hand away from the plate, will reduce the overall volume range, while setting the TP2 voltage to less than 2.5V will increase the overall range. Note that the TP3 voltage will have to be set to 7V again using trimpot VR3 (with your hand away from the disc) after setting T4's slug to give a new value at TP2.

## Pitch alignment

Now you are ready to align the pitch control. Set the volume potentiometer (VR1) slightly away from minimum setting. Set the telescopic antenna so that just the two larger sections are extended.

Using a suitable alignment tool, rotate the slug in transformer T1 slowly until a tone is heard in the loudspeaker. Then adjust it to obtain a good frequency range when your hand is brought near to the extended antenna. The note should be at its highest when your hand is close to the antenna and should fall to a very low frequency (just a growl) when your hand is taken away.

If the effect is the reverse of this (lower frequency as your hand is brought close to the antenna) then readjust the slug until the effect is correct.

Adjust voice trimpot VR2 so that you obtain the required sound from your Theremin. Note that adjustment at the fully clockwise setting will cause the pitch to lock to the reference oscillator for some movement of the hand before it snaps into sound. You can now adjust the tuning of the Theremin by carefully adjusting the antenna length from its normal length of the two fully extended largest sections.

Placing the loudspeaker and lid in position will change the tuning slightly, although adjusting the antenna length should be sufficient to retune correctly. If hand control over volume is affected, then readjust this tuning.

Note that if you connect the Theremin to an amplifier, the extra grounding will affect the tuning, but adjustment of the antenna length should correct this. ***EPE***

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# Reasons To Be Cheerful – And Concerned

TechnoTalk

Mark Nelson

**Are you shivering? Mark Nelson hopes he can warm the cockles of your heart with some good news on energy cost reduction. And then to chill your spine he offers an alarming report on the way plastic card transactions can be falsified. The 'ghost' transactions in people's bank statements perhaps have an explanation at last.**

THE bitter winter we've been having has given the climate change deniers ammunition for their contrarian views, and left householders wondering how they will be able to pay their inflated heating bills. Thoughtful commentators have pointed out that instead of wondering how we can afford expensive carbon reduction measures, the goal should surely be to reduce power consumption in new domestic, business and industrial gadgets.

Another mitigation measure for reducing power consumption is energy harvesting, on which we have touched previously. Ingenious solutions keep on coming and I felt I just had to bring two new wrinkles to your attention.

## Skutterudites are in

That's right, skutterudites. And I'll save you the effort of checking out Wikipedia and explain that skuterudite is a cobalt arsenide mineral that was first identified at Skuterud Mines, Norway, in 1845. Also known as smaltite, it occurs in Canada, the USA and other cobalt and nickel mining areas around the world.

So why are skutterudites noteworthy right now? Because when wrapped around your car's exhaust system, they could one day scavenge heat that would otherwise be wasted, turning it into energy to warm the interior or recharge the battery. Engineers and physicists at the University of Michigan are on the way to improving their thermoelectric efficiency by as much as 20 per cent, enough for commercialisation of this promising power source. The researchers have found that combining skutterudites with the metal barium creates a material that conducts electricity well and heat poorly.

According to physic professor Ctirad Uher, car companies are extremely interested in this technology. He states: 'The ideal environments for these materials are spots where large differences in temperatures exist. One such place is the pipe system of a car between the motor and the catalytic converter. That's a big source of heat that you've paid for already.'

Colleague Massoud Kaviany, professor in the Department of Mechanical Engineering, underscores the significance of their research, saying: 'Today's state-of-the-art thermoelectric materials are only five percent efficient. Skutterudites, and this new knowledge about how best to arrange their atoms, could help improve their performance to 15 or 20 per cent, at which point they become useful in many practical applications.'

## Energy harvesting

In Japan, Fujitsu Labs has developed a hybrid energy harvesting device that generates electricity from either heat or light. Using this single device it is possible to derive energy from two separate sources, which previously could only be handled by combining individual devices. Furthermore, the low cost of the organic materials used in this hybrid device should enable widespread use of these highly efficient energy-harvesting devices that Fujitsu hopes to commercialise within four years.

What they have developed is an organic material that operates in both photovoltaic and thermoelectric modes by switching the electrical circuits connecting *P*-type and *N*-type semiconductors. High generating efficiency means the device can produce power in photovoltaic mode, even from indoor lighting.

Full details are not yet available, but in medical fields, for example, the technology could be used in sensors that monitor conditions such as body temperature, blood pressure and heartbeats – without batteries and electrical wiring. The technology could also be used for environmental sensing (eg, for weather forecasting) in remote areas where it would be problematic to replace batteries or run electric power lines.

## Battery breakthrough

More good news; two months back we discussed the remarkable electronic, optical and thermal properties of graphene, the new wonder material that's a sheet or layer of carbon just one atom thick. Now comes the news that researchers at US-based Nanotek Instruments have created a graphene-based supercapacitor that can store as much energy as a nickel metal hydride battery, in the same space. Unlike the battery, however, it can be charged or discharged in just minutes or even seconds.

According to the Institute of Physics, the specific energy density of the device, g at room temperature, is the highest ever for electric double layer supercapacitors based on carbon nanomaterials. The device might be used to recharge mobile phones, digital cameras and micro electric vehicles – or the very first portable light sabre. Producing it cheaply and in volume is now the challenge.

## Chip-and-PIN in the news

Prepare to be annoyed and then seriously worried. This month (February) sees the opening of the fifteenth annual *Financial Cryptography and Data Security* conference in St Lucia (February 28 – March 4). You might see this as just another opportunity for overpaid bankers to enjoy a luxury break at their customers' expense, but believe me, it has some crucial consequences for you and me, assuming you use a chip-and-PIN credit or debit card.

The conference will include the first public reading of a paper on card security co-authored by controversial Cambridge University student Omar Choudary. Choudary has already upset the UK banking and card payment fraternity by revealing publicly a fundamental flaw in the chip-and-PIN system that allows transactions made with a stolen (and uncancelled) card to be 'verified by PIN' without knowing the card's original PIN code. Even worse, in the bankers' view, his MSc paper describes and illustrates a small hand-held device that he used to prove the vulnerability of card readers in retail premises.

As a self-made project, his 'EMV Interceptor' certainly earns my admiration for both ingenuity and extremely tidy workmanship. He designed and product-engineered his hand-held gizmo for under £100 and states that it could be produced commercially for about £20. It's a perfect example of 'practical electronics' and you can check out his handiwork at: **www.cl.cam.ac.uk/~osc22/docs/mphil_acs_osc22.pdf**, if you feel inclined.

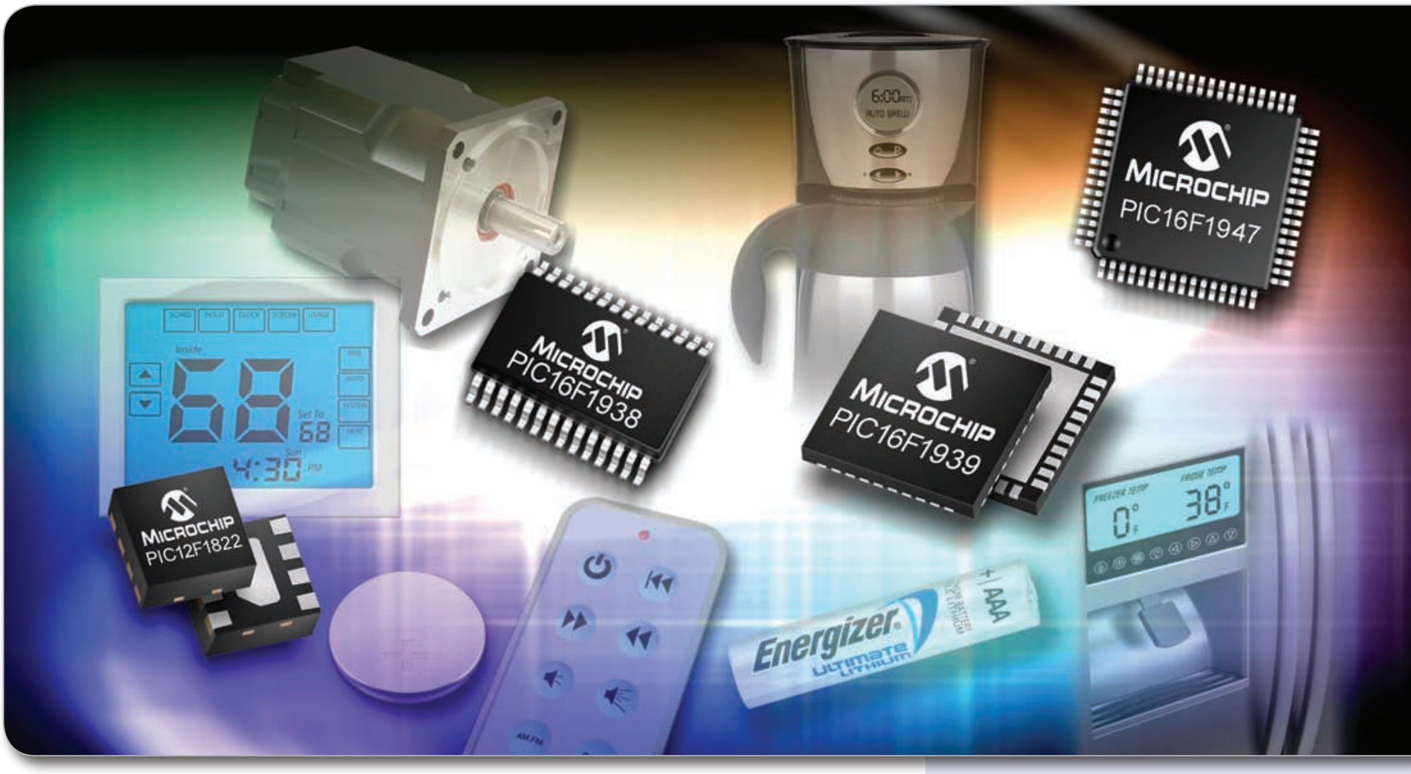
There is plenty for chip-and-PIN card users to be worried about, and the technology has not eliminated card fraud, only modified its nature. Card users have no control over the integrity of transactions and, to quote Choudary, it is possible for someone to tamper with the terminal such that the amount shown on the display differs from the amount requested to the card. The user will confidently enter the PIN and authorise the transaction. What's more, it's possible to use any card (your own or a stolen card) without knowing its PIN.

According to Ross Anderson, one of Choudary's supervisors and himself an expert on information security, only one bank has responded to this technical weakness. 'The No-PIN attack no longer works against Barclays' cards at a Barclays merchant,' he reports.

Not unnaturally, the UK Cards Association argues that Choudary's disclosures 'breach the boundary of responsible disclosure' but Anderson is not prepared to 'censor a student's thesis that is lawful and already in the public domain, simply because a powerful interest finds it inconvenient.' As bloggers have noted, the other banks have known about the flaw for a year, but chose not to fix it. Instead, the trade association demands that no-one draw attention to the door they've left unlocked for a year.

# Low-Power Microcontrollers for Battery-Friendly Design

## Microchip Offers Lowest Currents for Active and Sleep Modes




**Extend the battery life in your application using PIC® microcontrollers with nanoWatt XLP Technology and get the industry's lowest currents for Active and Sleep modes.**

Microchip's new peripheral-rich PIC12F182X, PIC16F182X and PIC16F19XX families offer active currents of less than 50 µA and sleep currents down to 20 nA. These products enable you to create battery-friendly designs that also incorporate capacitive touch sensing, LCD, communications and other functions which help differentiate your products in the marketplace.

Microchip's Enhanced Mid-range 8-bit architecture provides up to 50% increased performance and 14 new instructions that result in up to 40% better code execution over previous-generation 8-bit PIC16 MCUs.

### PIC12F182X and PIC16F182X families include:

- Packages ranging from 8 to 64 pins
- mTouch™ capacitive touch-sensing
- Multiple communications peripherals
- Dual I²C™/SPI interfaces
- PWM outputs with independent time bases
- Data signal modulator

### PIC16F19XX family includes:

- mTouch capacitive touch-sensing
- LCD drive
- Multiple communications peripherals
- More PWM channels, with independent timers
- Up to 28 KB of Flash program memory
- Enhanced data EEPROM
- 32-level bandgap reference
- Three rail-to-rail input comparators

## GET STARTED IN 3 EASY STEPS

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MICROCHIP


By JIM ROWE

# Low-Cost Digital Audio Millivoltmeter

## Indicates signal levels in mV, dBv and dBm

**Want to measure small signals at audio frequencies? Here's a low-cost digital audio millivoltmeter which will allow you to measure audio signals from below 5Hz to above 100kHz. As well as indicating the level in both millivolts and dBV, it also shows the corresponding dBm level into 600Ω.**

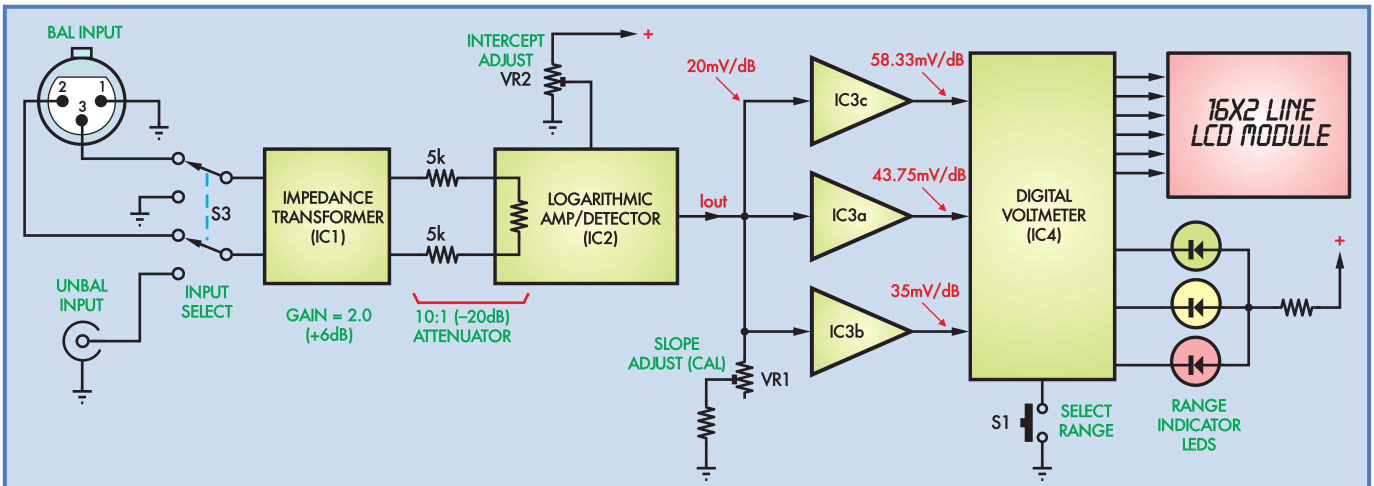



**Fig.1: block diagram of the Digital Audio Millivoltmeter. The audio signal is first fed to an impedance transformer stage (IC1) and then to a log amplifier/detector via a resistive attenuator. Its output is then fed to three different DC amplifiers, which in turn feed a digital voltmeter stage based on PIC microcontroller IC4 and an LCD module.**

THIS new audio millivoltmeter design is an adaptation of the RF Level and Power Meter described in the December 2010 issue of *EPE*. Like that design, it makes use of a logarithmic amplifier/detector IC (an AD8307) to provide a very sensitive detector. This has a DC output which is closely proportional to the logarithm of the audio input voltage.

We have combined one of these Analog Devices AD8307 chips with an instrumentation amplifier to provide it with a high input impedance, and also added an 'intelligent' metering circuit based on a PIC microcontroller. In operation, the PIC processes the detector's logarithmic DC output voltage to indicate signal level and the equivalent dBV and dBm levels.

The PIC micro uses some fairly fancy maths routines to work out the signal level, which is then displayed on a standard 2-line × 16-character LCD display. All the circuitry is on a single PC board and fits in a compact diecast aluminium case. The whole set-up works from an external 12V battery or plugpack, drawing less than 200mA (most of which is used by the backlighting in the LCD module).

## How it works

The block diagram of Fig.1 shows how the new meter works. At far left are the two input sockets, one for a balanced input and the other for an unbalanced input. Switch S3 allows one of these inputs to be selected, with the desired input fed to an impedance transformer stage. This uses an AD623 instrumentation amplifier (IC1) to provide a relatively high input impedance of 100kΩ and operates with a gain of two (+6dB).

The output of the impedance transformer stage is then fed to the AD8307 log amplifier/detector (IC2) via a 10:1 resistive attenuator. This attenuator is formed by the 5kΩ resistors in series with each input and the AD8307's own input resistance of 1100Ω.

The output of the log amp/detector is essentially a DC voltage, with a value closely proportional to the logarithm of the AC input voltage. In fact, the slope of the detector's output is very close to 25mV per decibel rise or fall in the input. By adjusting the log detector's load resistance via trimpot VR1, we can set the slope to 20mV/dB (for calibration).

Trimpot VR2 is used to adjust the DC voltage levels inside IC2 to set its effective zero-input setting. The output from the log detector is then fed to three DC amplifiers using IC3a, IC3c and IC3b. These are configured to provide three levels of voltage gain, and hence three measuring ranges.

IC3b provides a gain of 1.75, scaling the detector output slope to 35mV/dB (for the <0dBV range), while IC3a and IC3c provide gains of 2.1875 and 2.9165 respectively, giving output slopes of 43.75mV/dB and 58.33mV/dB for the <–20dBV and <–40dBV ranges.

Each of these scaled detector voltages is fed to a different analogue input of the digital voltmeter, which uses a PIC16F88-I/P microcontroller (IC4). Switch S1 allows the user to select which of the three analogue inputs is connected to IC4's 10-bit ADC (analogue-to-digital converter). The firmware running in IC4 then directs the ADC to measure the scaled detector output, performs the necessary calculations to work out the equivalent

## Specifications

- **Main Features:** a low-cost audio millivoltmeter based on a logarithmic amplifier/detector coupled to a digital metering circuit using a programmed PIC microcontroller and an LCD readout.
- **Input Impedance:** 100kΩ (balanced input can be changed to 600Ω)
- **Measuring Frequency Range:** from below 5Hz to above 100kHz
- **Maximum Input Signal Level:** 1.4V RMS (+3.0dBV, +5.2dBm/600Ω)
- **Minimum Input Signal Level:** 160µV RMS (–76dBV, –73.8dBm/600Ω)
- **Measurement Linearity:** approximately ±0.3dB
- **Measurement Accuracy:** approximately ±3%
- **Power requirements:** 12V to 5V DC at <200mA with backlit LCD

## Parts List – Digital Audio Millivoltmeter

1 PC board, code 794, available from the *EPE PCB Service,* size 160mm × 111mm
1 diecast aluminium box, size 171mm × 121mm × 55mm
1 front panel label – see Fig.7
1 2-line × 16-character LCD module, (Jaycar QP-5516, or Altronics Z-7012)
4 M3 × 25mm tapped spacers
4 M3 × 15mm tapped nylon spacers
1 SPST momentary pushbutton switch (S1)
1 SPDT mini toggle switch (S2)
1 DPDT mini toggle switch (S3)
1 panel-mount XLR type balanced audio plug (CON1)
1 panel-mount BNC socket (CON2)
1 PC mount 2.5mm concentric DC power socket(CON3)
1 7 × 2 length of DIL socket strip, or 14 × 1 length of SIL socket strip (half of 28-pin IC socket)
1 7 × 2 length of DIL terminal strip, or 14-way length of SIL terminal strip
1 18-pin IC socket
1 14-pin IC socket
2 8-pin IC sockets
4 M3 × 6mm machine screws, csk head
13 M3 × 6mm machine screws, pan head
1 M3 nut
1 M3 star lockwasher
1 M3 nylon flat washer
8 PC board terminal pins, 1mm dia.
1 1.2 metre length of 0.8mm dia. tinned copper wire

**Semiconductors**
1 AD623AN instrumentation amplifier (IC1)
1 AD8307AN log amplifier/ detector (IC2)
1 LM324 quad op amp (IC3)
1 PIC16F88-I/P microcontroller (IC4) programmed with 0410309A.hex firmware
1 LM317T adjustable regulator (REG1)
1 12V 1W Zener diode (ZD1)
1 1N4004 1A diode (D1)
1 3mm green LED (LED1)
1 3mm orange LED (LED2)
1 3mm red LED (LED3)

**Capacitors**
1 470µF 16V radial electrolytic
1 220µF 16V radial electrolytic
1 100µF 16V radial electrolytic
1 22µF 16V radial electrolytic
2 10µF 16V tantalum
1 10µF 16V radial electrolytic
2 2.2µF 35V tantalum
2 1µF 25V tantalum
1 220nF monolithic ceramic
5 100nF monolithic ceramic
1 100pF disc ceramic
1 10pF disc ceramic

**Trimpots**
2 50kΩ linear horiz. trimpot (VR1, VR2) – code 503
1 200Ω linear horiz. trimpot (VR3) – code 201
1 10kΩ linear horiz. trimpot (VR4) – code 103

**Resistors (0.25W, 1%)**

| | |
|---|---|
| 2 220kΩ | 1 2.4kΩ |
| 3 100kΩ | 1 2.2kΩ |
| 1 68kΩ | 3 2.0kΩ |
| 1 51kΩ | 1 1.5kΩ |
| 1 33kΩ | 2 470Ω |
| 5 10kΩ | 2 330Ω |
| 1 6.8kΩ | 1 200Ω |
| 2 4.7kΩ | 1 120Ω |
| 1 3.9kΩ | 1 100Ω |
| 1 3.0kΩ | 2 10Ω |

1 18Ω 0.5W – $R_{BL}$ (used with Altronics LCD module only)

AC input voltage and dB levels and then displays these on a 16-character × 2-line LCD module.

### Circuit details

Fig.2 shows the complete circuit of the Digital Audio Millivoltmeter. The 100kΩ resistors connected between the inputs (pins 2 and 3) of IC1 and the +6V half-supply rail provide a biasing path and also set the instrument's input resistance. The 2.2µF input coupling capacitors set the instrument's low-frequency limit to below 5Hz.

On the other hand, the 470Ω resistors in series with each input, together with the 10pF capacitor across the inputs, form a low-pass filter which rolls off RF signals which could disturb the operation of both IC1 and IC2. The 100kΩ resistor connected between pins 1 and 8 of IC1 sets its gain to 2.0.

The pin 6 output of IC1 is fed to the inputs of IC2 via a 10:1 attenuator formed by four 10kΩ resistors and the input resistance of IC2. The output coupling capacitors have a value of 10µF, to maintain the low frequency response, while the 100pF capacitor across the inputs of IC2 provides a further measure of RF rejection.

### PIC microcontroller

The rest of the circuit is straightforward, with most of the real work done by the firmware running inside PIC micro IC4. The PIC16F88-I/P device is well-suited to this application, because it includes an ADC module with 10-bit measuring resolution. The ADC is also flexible in terms of its operating mode, with a choice of positive and negative reference voltages and a 7-channel input multiplexer.

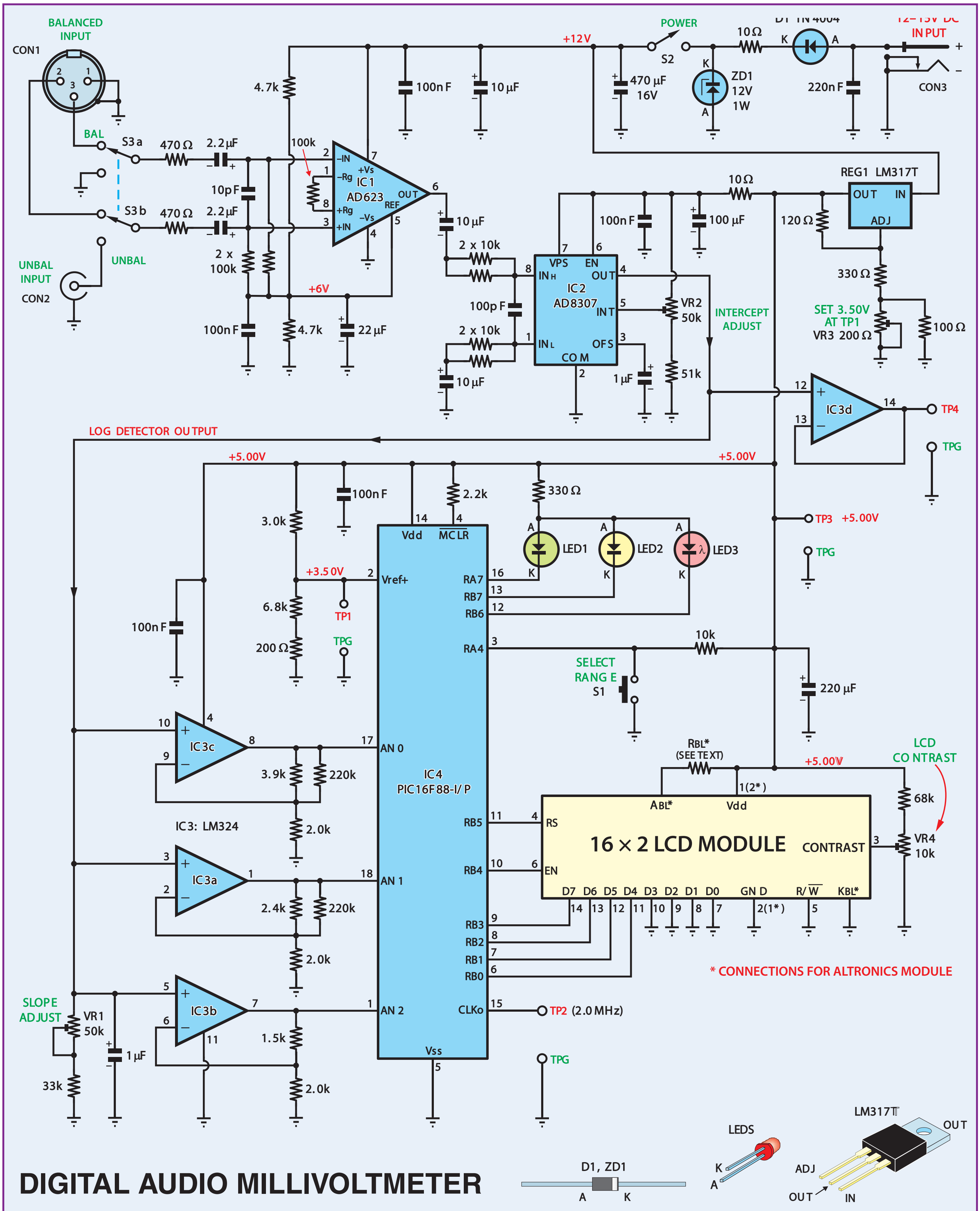
We take advantage of these features by using our own positive reference voltage of 3.50V (fed into pin 2) and also by using three of the ADC input channels to allow firmware selection of the measuring range via pin 1 (AN2), pin 18 (AN1) and pin 17 (AN0).

We select the ranges inside the PIC simply by selecting the appropriate ADC input channel (AN2, AN1 or AN0). The firmware does this input selection by stepping from one range to the next each time you press S1, the range select button. To indicate which range is currently selected, the firmware switches on LED1, LED2 or LED3. The firmware automatically changes the scaling factor used for each range, so that the displayed values are correct.

Finally, the LCD module is driven directly by the PIC in standard '4-bit interface' fashion.

### Power supply

Most of the circuit runs from +5V DC, derived from either a nominal 12V battery or a 12V to15V plugpack supply. The only part of the circuit which runs directly from the 12V input voltage is IC1, which needs the higher voltage to handle the full input signal levels.




## DIGITAL AUDIO MILLIVOLTMETER

Fig.2: this is the complete circuit of the Digital Audio Millivoltmeter. The input impedance-matching stage is based on IC1, which is an AD623AN instrumentation amplifier. IC2, an AD8307AN, is the log/amplifier detector, and this feeds op amps IC3a to IC3c, which operate with different gains to provide the three ranges. IC4, a PIC16F88-I/P microcontroller does the 10-bit analogue-to-digital conversion (among other things) and drives the 2-line × 16-character LCD module.

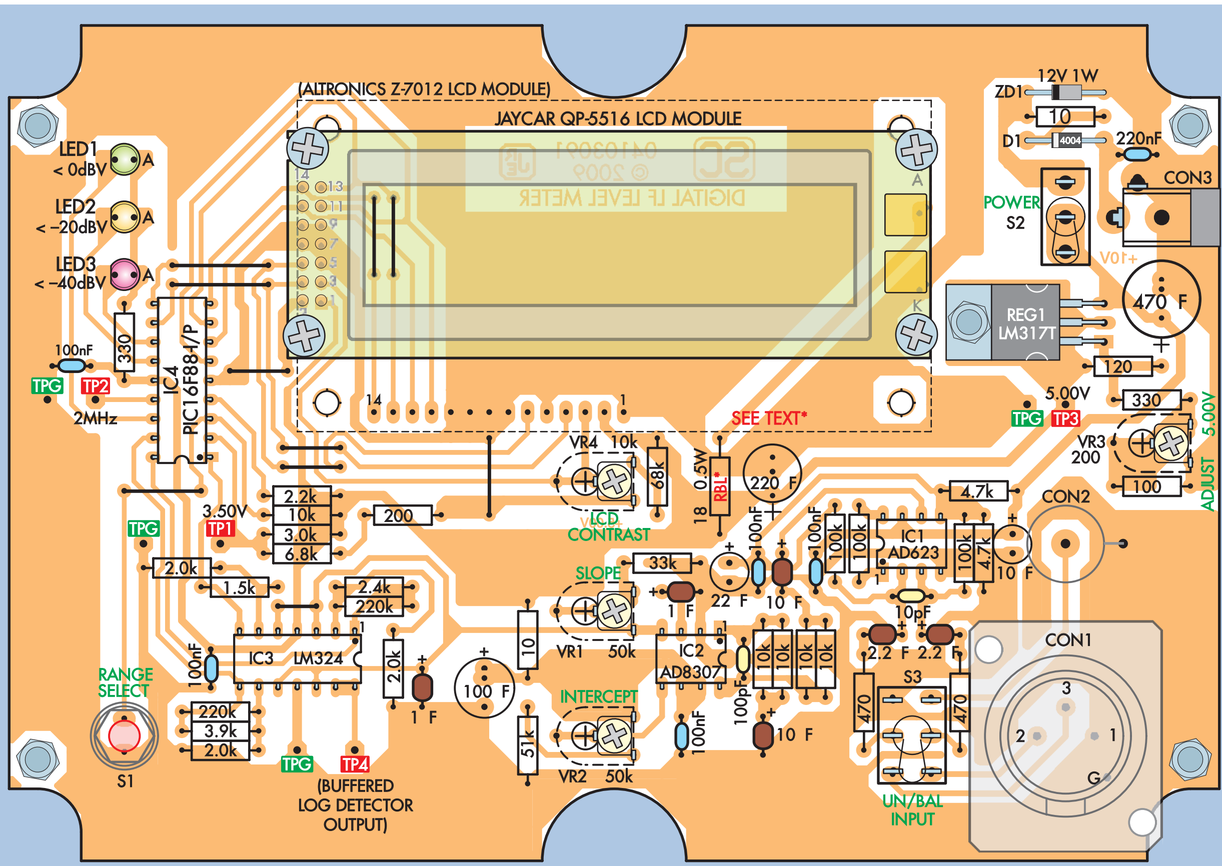



**Fig.3: follow this layout diagram to assemble the unit. Note that neither connectors CON1 and CON2, nor switches S1 to S3 are mounted directly on the board. Instead, they are first mounted on the case lid and fitted with tinned copper wire 'extension leads'. The leads then pass through the relevant board holes when the board is mounted on the lid.**

The +5V rail is obtained using an LM317T adjustable regulator. This allows us to adjust the supply rail to accurately set the +3.50V reference voltage for the PIC's ADC. This +3.50V reference is derived directly from the +5V rail via a resistive voltage divider consisting of 3.0kΩ, 6.8kΩ and 200Ω resistors. This reference voltage for the ADC is fed into pin 2 of the PIC, which is configured as the Vref+ input.

## Test points

Notice that there are a number of test points provided on the PC board, to allow more convenient set-up and calibration. TP1 allows you to measure the ADC reference voltage, so you can adjust trimpot VR3 to achieve exactly +3.50V at pin 2 of the PIC. TP3 also allows you to measure the +5.00V rail directly, if you wish, while TP2 allows you to check the PIC's internal clock oscillator.

In this project, we run the oscillator at 8MHz, which means that the signal available at TP2 should be very close to 2MHz (Fc/4). So, if the PIC is running correctly, you will find a 2MHz square wave of 5V peak-to-peak at TP2.

The fourth test point (TP4) is provided to allow monitoring of the log detector's DC output voltage with an external DMM. Op amp IC3d is configured as a unity-gain voltage follower, making the voltage at IC2's pin 4 output available at TP4 without any significant loading and disturbance to circuit operation.

## Construction

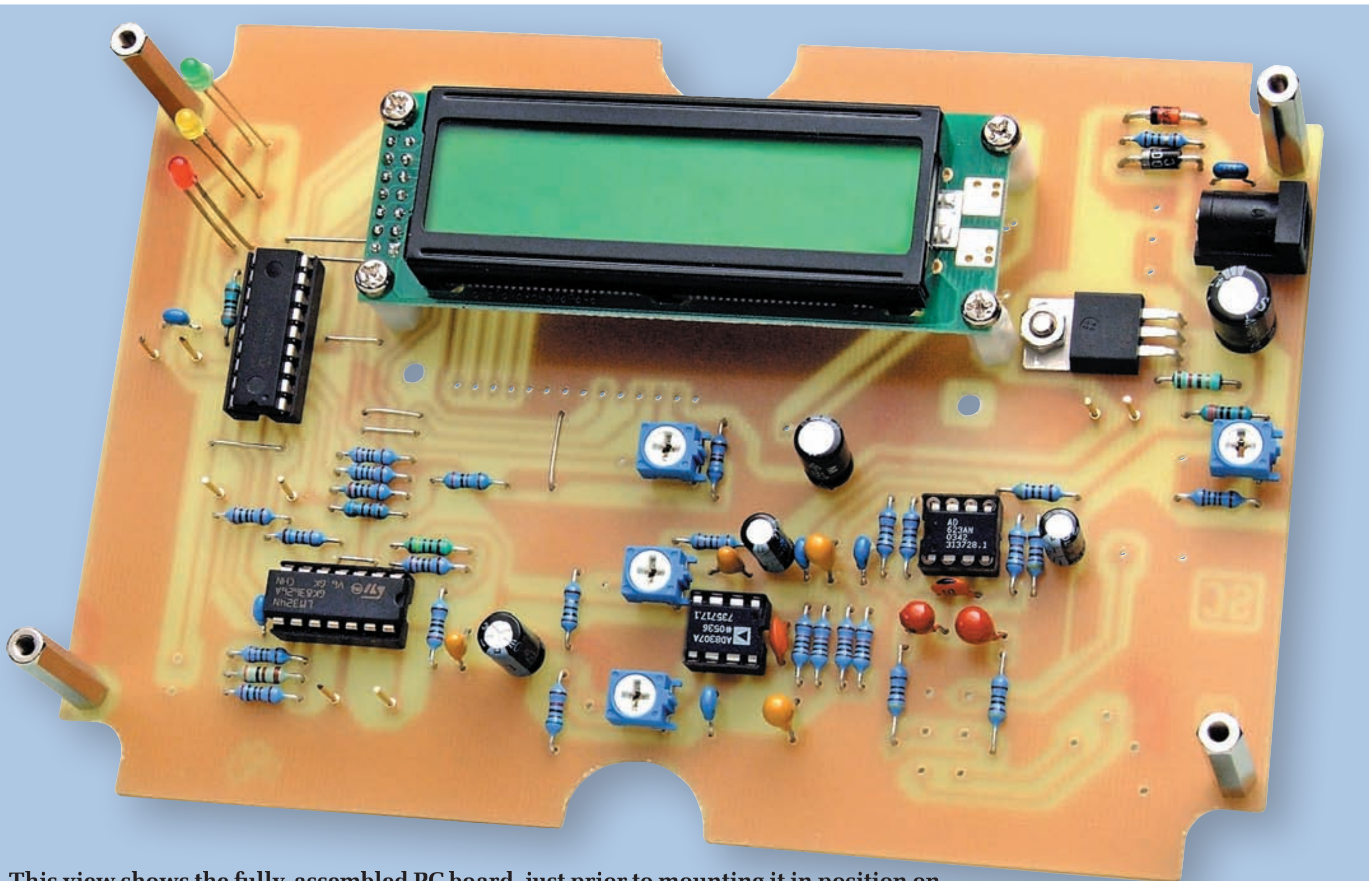
As noted earlier, virtually all of the circuitry in the project is mounted on a single PC board, which mounts inside a diecast aluminium case (171mm × 121mm × 55mm) for shielding. The PC board measures 160mm × 111mm and is coded 794. This board is available from the *EPE PCB Service.*

As shown in the photos, the LCD module (Jaycar QP-5516 or Altronics Z-7011) mounts above the main board in the upper centre, while the complete assembly mounts behind the lid of the case on 25mm spacers. The switches and input connectors mount directly on the lid, which therefore forms the instrument's front panel.

Fig.3 shows the parts layout on the PC board. Note that DC input connector CON3 is the only connector mounted directly on the board. The three range indicator LEDs are also mounted directly on the board, with the underside of their bodies spaced up by about 24mm. They (just) protrude through matching holes in the lid when the board is mounted behind it. Sockets are used for all four ICs, rather than soldering them directly to the board.

There are 10 wire links on the board, and it's a good idea to fit these before any of the components, so they're not forgotten. Note that two of the links are fitted under the footprint of the LCD module, at upper left. However, these two links are only required if you use the Altronics Z-7011 SIL module.

The test point terminal pins can also be fitted at this early stage, along with the IC sockets. Make sure you mount the latter with their orientation as shown in Fig.3, so they'll guide you in plugging in the ICs later.



This view shows the fully-assembled PC board, just prior to mounting it in position on the case lid. Make sure that all polarised parts (including the three ICs) are correctly orientated, and note that IC1 and IC2 face in opposite directions.

Next, fit DC input connector CON3, which goes in at upper right. It's then a good idea to fit the connector for the LCD module you're using. If you're using the Jaycar LCD module, this means that a 7 × 2 piece of DIL socket strip must be fitted with a north-south orientation at the left-hand end of the module's footprint – see Fig.3.

Alternatively, if you're using the Altronics (single in-line version) module, this needs a 14 × 1 section of SIL socket strip (made from one side of a 28-pin IC socket). This strip is fitted with an east-west orientation at lower left within the module's footprint (just above the position for trimpot VR4).

Follow this by fitting the four trimpots (VR1 to VR4). These are all horizontal mounting types, and the board allows either the small open type or the even smaller sealed type. Note that the two 50kΩ trimpots go in the VR1 and VR2 positions, while the 200Ω trimpot is used for VR3. A 10kΩ trimpot is used for VR4 and is the LCD module's contrast adjustment.

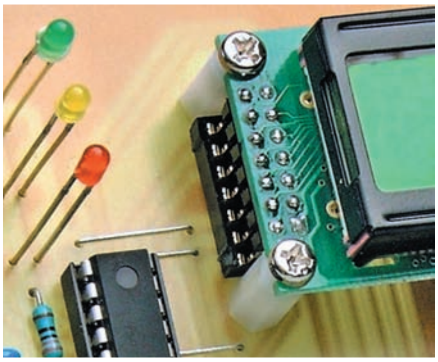
Once all four trimpots are fitted, you can fit the resistors, making sure that you fit each one in its correct position, as shown in Fig.3. **Note that the resistor labelled '$R_{BL}$' (18Ω 0.5W) is the current-setting resistor for the Altronics LCD module's back lighting. It's not needed if you use the Jaycar module.**

The disc ceramic and monolithic capacitors should be fitted next. These are then followed by the tantalum and electrolytic capacitors, which are polarised – so take care to fit them with the orientation shown in Fig.3.

Now fit diode D1 and Zener diode ZD1, followed by regulator REG1. Note that the latter is a TO-220 device, and is mounted with its body flat against the top of the board. To do this, you will first have to bend its three leads down by 90° about 6mm from its body. That done, secure it to the board using an M3 × 6mm machine screw and nut before soldering its leads.

## LCD mounting

The LCD module can now be prepared for mounting on the main board, by fitting it with either a 7 × 2 DIL pin header or a 14 × 1 SIL pin header; depending on the LCD module you use. In both cases, the header pins are passed up through the matching connection holes in the module from below, until the upper ends of their pins are just protruding from the top of the LCD module board. All 14 pins are then carefully soldered to the pads



**The LCD module is fitted with header pins and plugged into a matching socket on the PC board – see text. This photo shows the arrangement for the Jaycar module (7 × 2 DIL header).**

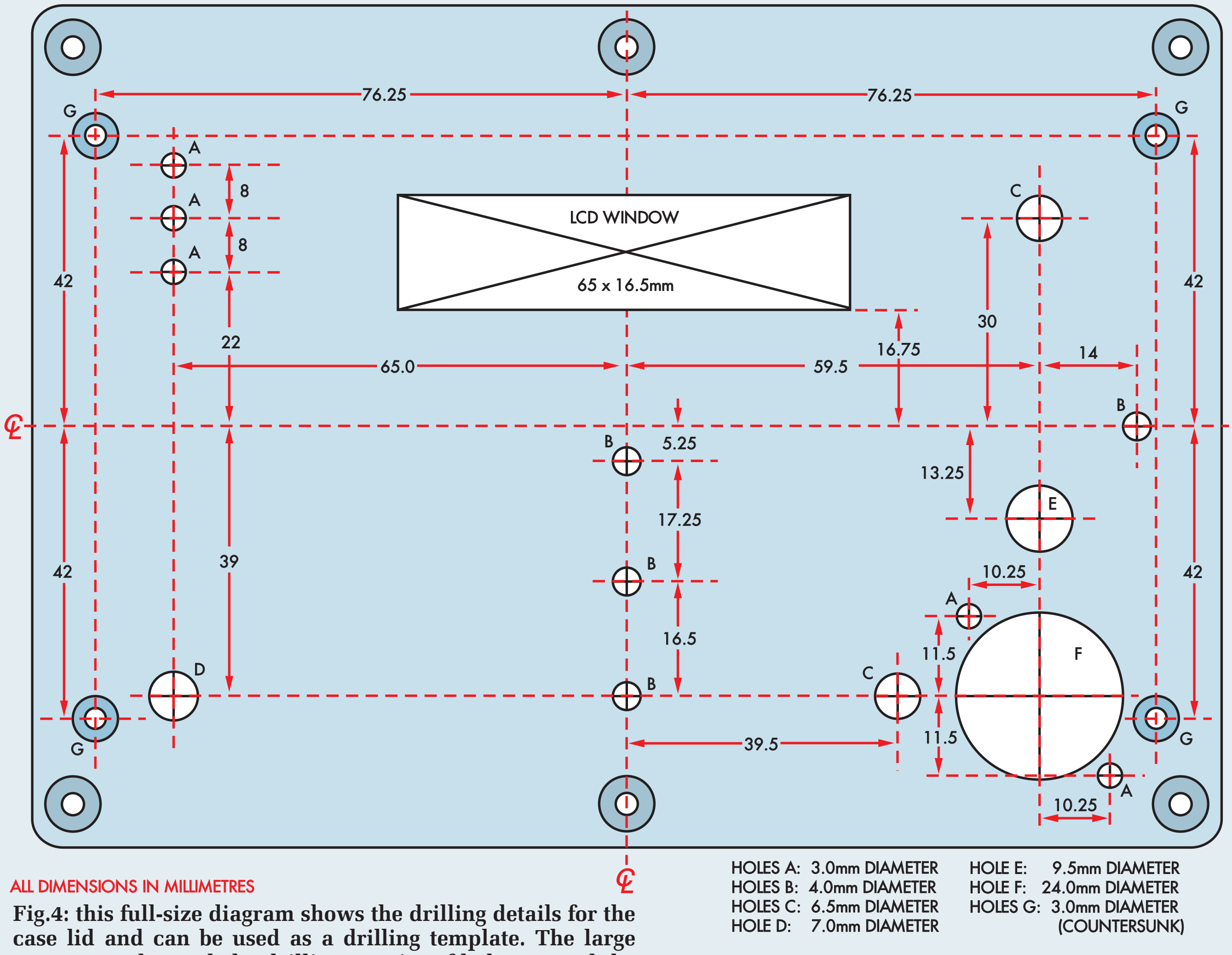



**Fig.4: this full-size diagram shows the drilling details for the case lid and can be used as a drilling template. The large cutouts can be made by drilling a series of holes around the inside perimeter, then knocking out the centre piece and filing the job to a smooth finish.**

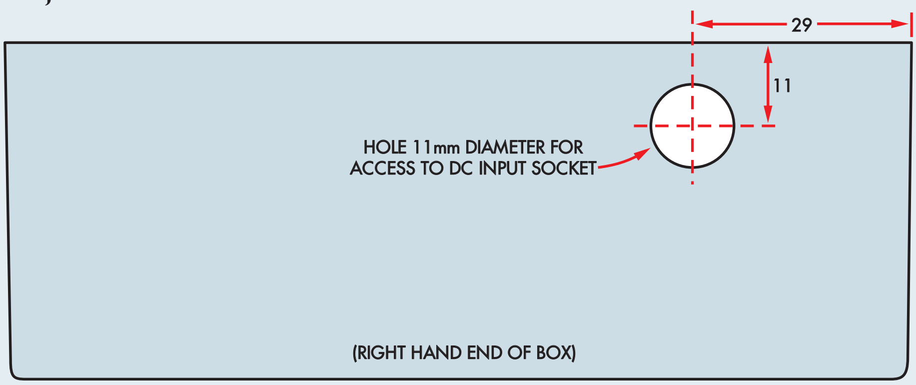



**Fig.5: an 11mm diameter hole is required in the right-hand end of the case to provide access to the DC power socket on the PC board.**

on the top of the board using a fine-tipped iron and just enough solder to make a good joint.

The next step is to mount four M3 × 12mm tapped nylon spacers on the main board to support the LCD module. These spacers must go in the correct positions to match the module you are using, and are attached using four M3 × 6mm machine screws. The LCD module is then mounted on top of these spacers, with its 14-pin 'plug' mating with the matching socket on the main board. Four more M3 × 6mm screws are then used to hold the LCD module in place.

**Note that if you are using the Altronics Z-7012 LCD module, you will also have to connect its 'A' and 'K' terminals (for the backlight LEDs) to the corresponding pads immediately below on the PC board. This can be done using short lengths of tinned copper wire.** These connections are not necessary for the Jaycar module.

The last components to mount on the board are the three range-indicator

**Table 1: Resistor Colour Codes**

| o | No. | Value | 4-Band Code (1%) | 5-Band Code (1%) |
|---|---|---|---|---|
| o | 2 | 220kΩ | red red yellow brown | red red black orange brown |
| o | 3 | 100kΩ | brown black yellow brown | brown black black orange brown |
| o | 1 | 68kΩ | blue grey orange brown | blue grey black red brown |
| o | 1 | 51kΩ | green brown orange brown | green brown black red brown |
| o | 1 | 33kΩ | orange orange orange brown | orange orange black red brown |
| o | 5 | 10kΩ | brown black orange brown | brown black black red brown |
| o | 1 | 6.8kΩ | blue grey red brown | blue grey black brown brown |
| o | 2 | 4.7kΩ | yellow violet red brown | yellow violet black brown brown |
| o | 1 | 3.9kΩ | orange white red brown | orange white black brown brown |
| o | 1 | 3.0kΩ | orange black red brown | orange black black brown brown |
| o | 1 | 2.4kΩ | red yellow red brown | red yellow black brown brown |
| o | 1 | 2.2kΩ | red red red brown | red red black brown brown |
| o | 3 | 2.0kΩ | red black red brown | red black black brown brown |
| o | 1 | 1.5kΩ | brown green red brown | brown green black brown brown |
| o | 2 | 470Ω | yellow violet brown brown | yellow violet black black brown |
| o | 1 | 200Ω | red black brown brown | red black black black brown |
| o | 1 | 120Ω | brown red brown brown | brown red black black brown |
| o | 1 | 100Ω | brown black brown brown | brown black black black brown |
| o | 2 | 10Ω | brown black black brown | brown black black gold brown |

LEDs. These all mount vertically with their longer anode (A) leads to the right, towards the LCD module. The leads are all left at their full lengths, so the bottom of each LED's body is very close to 24mm above the board.

Note that the green LED goes in the uppermost position as LED1, with the orange LED in the centre (LED2) and the red LED at the bottom (LED3).

After the LEDs have been mounted, it's time to plug the four ICs into their sockets. Take special care to orientate each IC correctly, as shown in Fig.3. In addition, take care to ensure that all the pins go into the sockets and that none go down the outside of the socket or are folded back under the IC.

Take your time here – the AD623 and AD8307 devices are fairly pricey, and the PIC micro isn't exactly cheap either.

## Preparing the case

Your board assembly will now be complete and can be placed aside while you prepare the meter's front panel. This involves drilling and cutting quite a few holes in the case lid, as shown in Fig.4. Most are easily drilled, the two exceptions being the rectangular cutout for the LCD viewing window and the 24mm main hole for the XLR balanced input connector.

These are best cut by drilling a series of 3mm holes around the inside of the cutout outline, and then using a small needle file to join the holes and allow the centre piece to be removed. A small file is then used to smooth the inside of the cutouts. It's tedious, but if you take your time, this method gives a good result.

You also have to drill a single hole in the right-hand end of the box itself, to give access to the DC input socket. The location and diameter of this hole is shown in Fig.5.

## Front panel

Once all of the holes have been cut in the lid, de-burred and countersunk where appropriate (eg, holes 'G' in Fig.4), you're ready to apply the front panel label. This can be made by photocopying the artwork shown in Fig.7 onto an adhesive-backed A4 sheet label, then applying a protective film (such as 'Contac').

It's now just a matter of cutting it to shape before peeling off the backing and applying it to the carefully cleaned lid. When it has been smoothed down, you can cut out the holes in the label using a sharp hobby knife.

With the front panel now complete, you can mount switches S1, S2 and S3 in position, followed by input connectors CON1 and CON2. Note that connector CON 1 mounts with its flange on the underside of the lid (see photo). It may be necessary to file away one corner of the flange in order to do this.

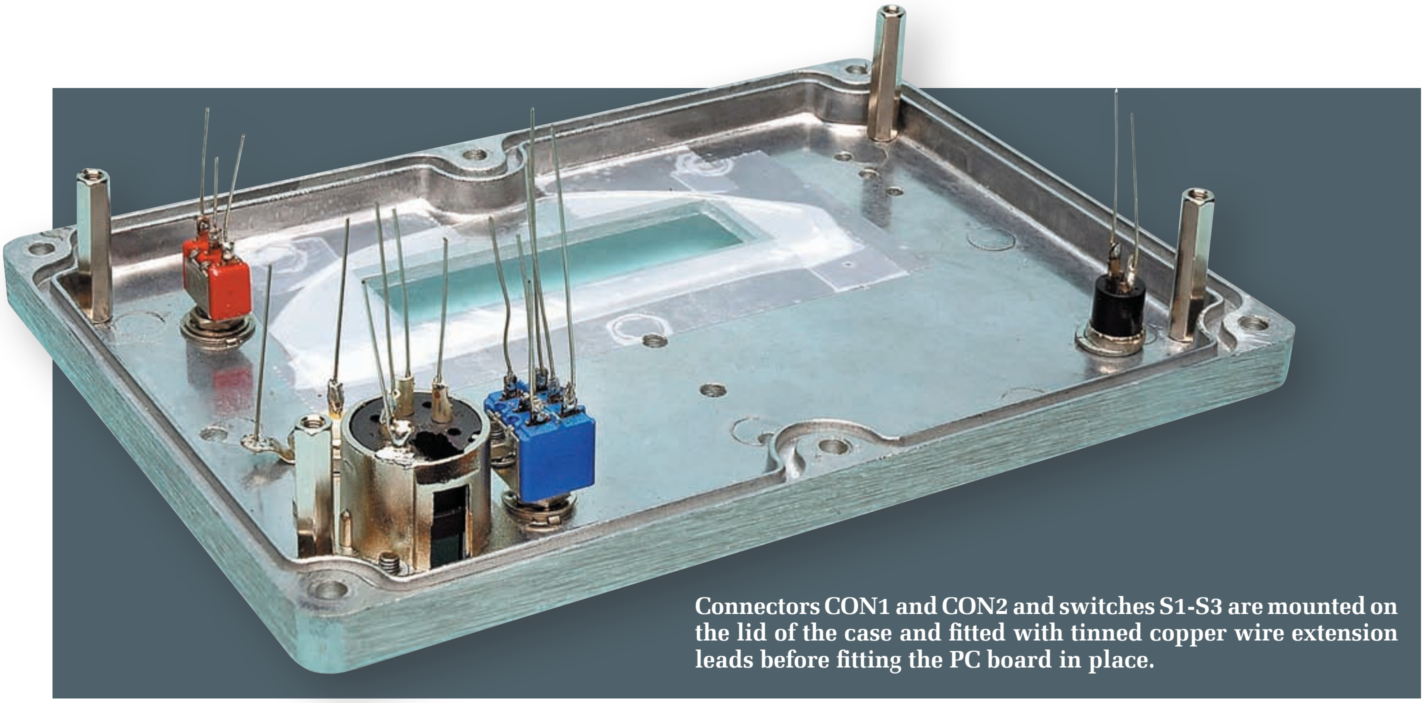
## Extension wires

You now have to fit each of the connection lugs on the rear of these switches and connectors with short 'extension leads', long enough to pass through their matching holes in the PC board when it's mounted behind the panel.

The best approach here is to use 40-60mm lengths of tinned copper wire for these extensions. Each of these is soldered at one end of a switch or connector contact lug and orientated vertically, ready to be passed through the board holes. **Make each extension wire a different length, as this will make it easier to get them through the board holes.**

**Note that you will also have to shorten the existing earth lug on the 3-pin XLR socket before fitting its extension lead, to prevent it later fouling the PC board.**

You should now be ready to mount the board to the rear of the front panel. To do this, first attach four M3 x 25mm tapped spacers to the front panel, using four M3 × 6mm countersink-head screws to secure them (these pass through 'G' in Fig.5). That done, carefully offer up the PC board assembly to the rear of the front panel, taking care to ensure that the wire extension leads from the switches and input connectors all pass through their matching holes in the board.



Connectors CON1 and CON2 and switches S1-S3 are mounted on the lid of the case and fitted with tinned copper wire extension leads before fitting the PC board in place.

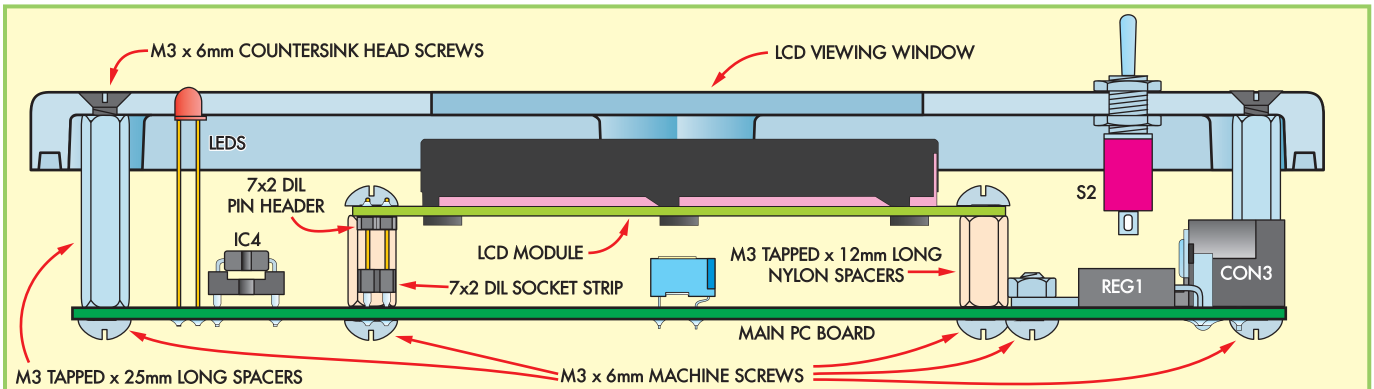



**Fig.6: the PC board is attached to the lid of the case via four M3 × 25mm tapped spacers, as shown here. Four M3 × 6mm countersink-head screws secure the lid to the spacers, while four M3 × 6mm pan-head secure the PC board.**

**This photo shows how the tinned copper wire extension leads soldered to the switches and connectors pass down through the PC board. Use a pair of long-nose pliers to guide each lead through its hole as the board is placed in position.**

At the same time, you also need to ensure that LEDs 1 to 3 each pass through their respective holes in the upper left of the panel.

Once the board is in position against the spacers, secure it in place using four M3 × 6mm pan-head screws – see Fig.6. Note that it's a good idea to place a star lockwasher under the head of the screw nearest to CON1, to ensure a good connection between the board's input earth copper and the metal of the case lid.

Having secured the board in place, the assembly can be upended and all the switch and input connector extension wires soldered to their corresponding board pads. The board and front panel assembly will now

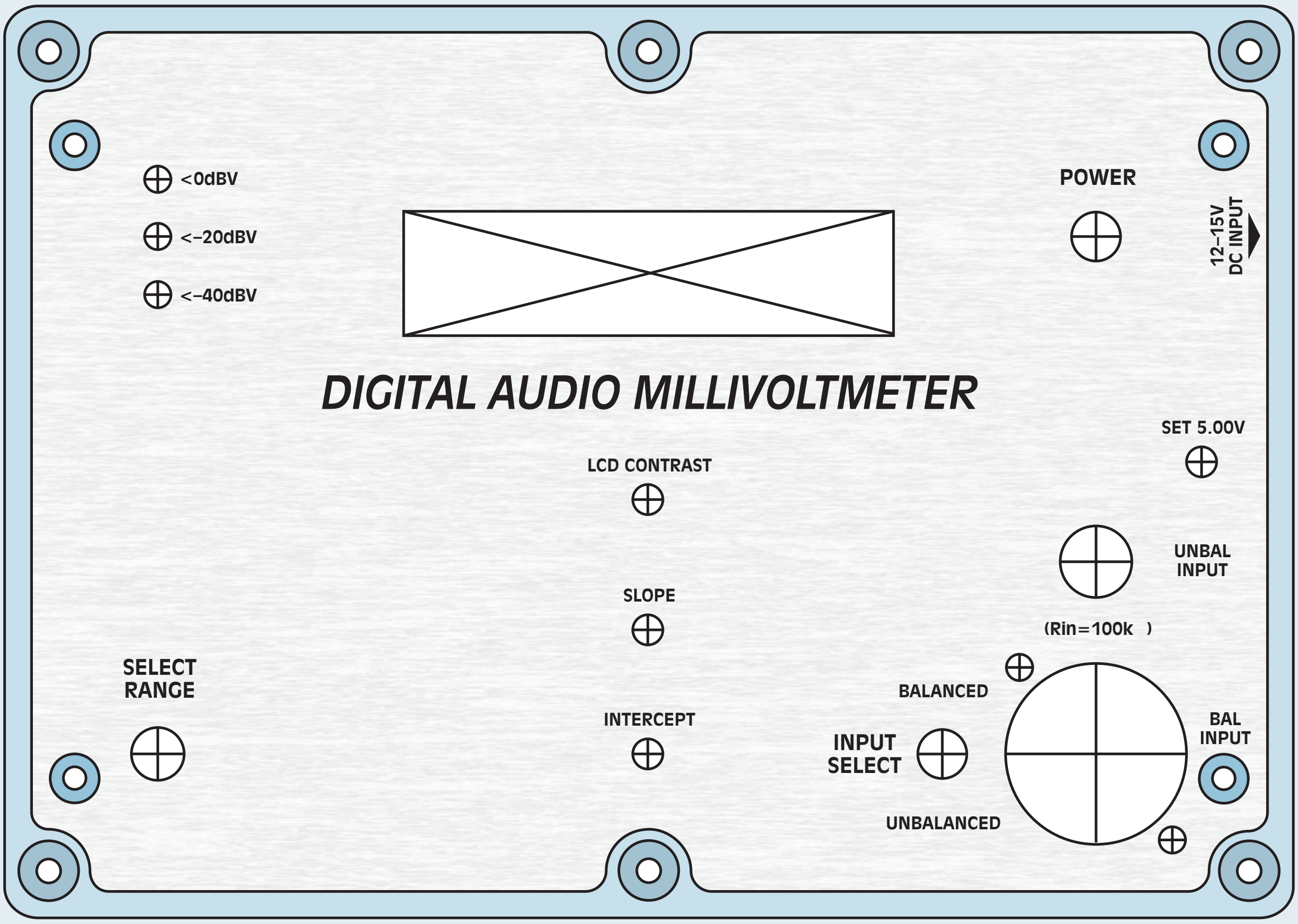



**Fig.7: this full-size artwork can be copied and used to make the front panel. Cover it with a protective film before attaching it to the case lid.**

be complete and ready for its initial checkout.

## Initial checkout

Your Digital Audio Millivoltmeter should now be given a preliminary functional checkout, as this is best done before the front panel/board assembly is attached to the case.

To begin, use a small screwdriver or alignment tool (passing down through holes 'B' in the front panel) to set trimpots VR1 to VR4 to their centre positions. After this, use a suitable DC cable to connect CON3 to a suitable source of 12V to 15V DC, which can be either a 12V battery or a nominal 12V DC plugpack.

Next, apply power and check that LED1 lights. There should also be an announcement message reading 'Silicon Chip AF Millivoltmeter' on the LCD, although you may have to adjust trimpot VR4 before this message is displayed with good contrast.

Note that this greeting message only lasts for a few seconds, after which it is replaced by the meter's normal display of readings.

If all is well so far, now is the time to set the voltage regulator so that the PIC's ADC reference voltage sits at exactly +3.50V. This is easy to do: just connect your DMM to TP1 and to its nearby TPG pin and adjust trimpot VR3 until you get a reading as close as possible to 3.500V. Use your most accurate DMM for this, because to a large extent the accuracy of this setting will determine the accuracy of your millivoltmeter.

That basically completes the initial set-up, although if you have access to a scope or a frequency counter you may want to check the PIC's clock signal at TP2. You should find a 5V peak-to-peak squarewave with a frequency very close to 2MHz.

After this initial checkout, you are ready to mount the front panel/board assembly in the case. Secure it using the six M4 countersink-head screws supplied. Note that although a length of neoprene rubber may be supplied for use as a seal between the case and its lid, there's no need to use this seal here. In fact, the box will provide better shielding if the seal is left out.

## Final adjustment

Your Digital Audio Millivoltmeter is now ready for the final step, which is adjustment and calibration. To do this, you'll need an audio signal generator of some kind, able to supply an audio sinewave signal of known level.

If you don't have access to a calibrated generator, an alternative is to use an uncalibrated oscillator with another audio measuring instrument of some kind, so that you can adjust its output to a convenient level (eg, 1.0V or 100mV RMS).

The calibration process is straightforward. Here's the step-by-step procedure:

**Step 1:** set switch S3 to select unbalanced input connector CON2, then fit a 50Ω termination load plug to CON2

## What the meter's PIC firmware does

As we explained in the main text, the AD8307 chip in the Digital Audio Millivoltmeter detects the incoming audio signals and converts them into a DC voltage according to a logarithmic conversion scale. It is this log-scale DC voltage which the PIC micro then measures and converts into the equivalent voltage and dB readings, under the control of the author's firmware program.

As you can imagine, the program directs the PIC to perform a number of maths calculations. To do this, it makes use of a suite of maths routines made available to PIC programmers by Microchip Technology, the manufacturer of the PIC family of micros. These routines are used to perform 24-bit and 32-bit floating point (FP) addition, subtraction, multiplication and division, base-10 exponentiation, fixed-point multiplication and division, and floating-point to ASCII conversion.

In essence, the PIC firmware program works through the following sequence in making each measurement:

First, it directs the PIC's 10-bit analogue-to-digital converter (ADC) module to take a measurement of the DC output voltage from the AD8307 chip. It then takes that measurement and converts it into 24-bit floating point form, after which it is multiplied with a pre-calculated scaling factor (24-bit also) for the currently chosen measurement range.

The resulting product is then divided by the ADC's full-scale 10-bit value of 3FF (in 24-bit FP form), to give the measurement value in what I call 'raw dB' form. This is essentially a 24-bit number varying between 0 and 100.

This raw dB value is then used to calculate the equivalent dBV value, by subtracting decimal 96.4782 (in 24-bit FP form), and also the equivalent dBm value (for a 600Ω impedance level) by subtracting decimal 94.2602 (again in 24-bit form). These values are then saved for display.

The dBV value is also used to calculate the actual voltage level. This is done by first dividing it by decimal 20 (in 24-bit FP form) and then raising decimal 10 to that power using 'EXP1024', Microchip's 24-bit floating point base-10 exponentiation routine. This is equivalent to calculating the antilogarithm, so we end up with the equivalent voltage value in 24-bit FP form. This is then saved for display.

Once the three parameters have been calculated, the final steps of the measurement sequence involve taking each 24-bit parameter and processing it for display on the LCD module. For the dBV and dBm figures, this means working out the correct polarity indication (+ or –) and then using a Microchip routine called 'Float_ASCII', to convert the numbers themselves into ASCII digits for display.

Things are a little more complicated for the voltage value, because this must first have its 24-bit binary exponent analysed to work out the scaling, the position of the decimal point and the most convenient multiplier to give it (eg, volts or millivolts). After this is done, it is again converted into the equivalent ASCII digits using Float_ASCII.

As you can see, there's quite a bit of mathematical 'jiggery-pokery' involved, but most of this is performed by Microchip's fancy maths routines. By the way, the full source code for the firmware will be available on the EPE website, along with the source code for the floating point maths routines it uses (in a file called 'FPRF24.TXT'). The assembled hex code of the complete firmware will also be available, ready to burn into a PIC.

## All about volts, dBV and dBm

The Audio Millivoltmeter described in this article gives three indications for every measurement: the audio input level in volts or millivolts and the corresponding values in dBV and dBm. The voltage level needs no explanation, but we should explain the significance of the two decibel figures.

For many years, electronics engineers have found it convenient to describe signal amplitude in decibels, because of the very wide ranges involved – from microvolts (μV) to kilovolts (kV). Because decibel scales are logarithmic, they make it easier to work with signals varying over such wide ranges.

For example, to describe the voltage gain of an audio amplifier in decibels, we take the base-10 logarithm of the voltage gain ($V_{out}/V_{in}$) and multiply this figure by 20. So a voltage gain of 10 corresponds to +20dB, a gain of 100 corresponds to +40dB, a gain of 1000 corresponds to +60dB and so on.

Similarly, an attenuator which reduces the voltage level by a factor of 10:1 can be described as having a 'gain' of –20dB.

### dBV and dBm

But what's the difference between the 'dBV' and 'dBm' figures? These are both decibel scales, but they are used to compare a specific voltage level with a known reference value, rather than to compare two specific values. So the contractions dBV and dBm indicate that the figures they accompany are absolute, rather than relative.

A reading in 'dBV' is a voltage expressed in decibels with reference to 1.0V. So +6dBV means a voltage that is 6dB greater than 1.0V (ie, 2.00V), while –20dBV means a voltage that is 20dB smaller than 1.0V (ie, 100mV) and so on.

Similarly, 'dBm' means that a signal level is being expressed in decibels with reference to a specific power level of 1mW (milliwatt) – in other words, on a decibel scale where 1mW corresponds to 0dB. So +10dBm corresponds to 10mW, +20dBm to 100mW and –30dBm to 1μW (microwatt).

Since the dBV and dBm scales are 'absolute', can they be related to each other? Yes they can, but to work this out you need to know the impedance level, because this is what relates voltage and power in any circuit.

In traditional audio work, the impedance level is 600Ω. At this level, a voltage of 1V corresponds to a power level of 1.667mW ($1^2/600$), so 0dBV equals +2.218dBm. So at this impedance level, there's a fixed 2.2dB difference between dBm and dBV.

Older audio level meters often indicated in just dBm or perhaps in dBV as well. If the user wanted to know the actual voltage level, they had to refer to a chart or grab a calculator and work it out.

This could be pretty tedious and that's why we've given this new Digital Audio Millivoltmeter the ability to calculate and display not just dBV and dBm (for 600Ω circuits) but the equivalent voltage level as well, for every measurement.

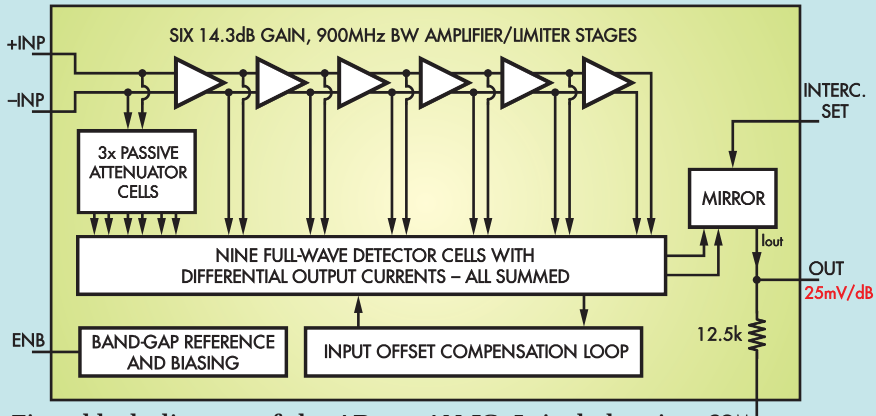



**Fig.8: block diagram of the AD8307AN IC. It includes six cascaded amplifier/limiter stages with a total gain of 86dB.**

## The AD8307 log amplifier/detector

You may not be too familiar with logarithmic amplifier/detector ICs because they are fairly specialised devices. But you can get an idea of how they work from Fig.8, which gives a simplified view of what's inside the AD8307AN device.

The incoming AC signals are passed through six cascaded wideband differential amplifier/limiter stages, each of which has a gain of 14.3dB (about 5.2 times) before it enters limiting. This gives a total amplifier gain of about 86dB, or about 20,000 times. The outputs of each amplifier/limiter stage are then fed to a series of nine full-wave detector cells, along with similar outputs from three cascaded passive 14.3dB attenuator cells connected to the input of the first amplifier/limiter.

The differential current-mode outputs of all nine detector cells are added together and fed to a 'current mirror' output stage, which effectively converts them into a single-sided DC output current. And because of the combination of cascaded gain and limiting in the amplifiers (plus an internal offset compensation loop), the amplitude of this output current turns out to be quite closely proportional to the logarithm of the AC input voltage, over an input range of just on 100dB – ie, from about –93dBV (22.4µV) up to +7.0dBV (2.24V).

In fact, this 'logarithmic law' relationship is linear to within ±0.3dB over most of the range. The output current $I_{out}$ increases at a slope of very close to 2µA per dB increase in AC input level, and when this current passes through a 12.5kΩ load resistor inside the chip, this results in a DC output voltage which increases at the rate of 25mV/dB. This slope can be fine-tuned using an adjustable external resistor in parallel with the internal 12.5kΩ resistor.

The 'intercept set' input allows us to adjust the DC offset in the output current mirror, which adjusts the effective 'zero level' point of the chip's output current and voltage – ie, the 'origin' from which the output slope rises. You can think of it as setting the detector's zero point.

so that the meter has a nominal audio input of 'zero'.

**Step 2:** apply power and monitor the LCD readout after the greeting message has been replaced by the normal readings. In particular, look at the dBV reading, because initially you'll probably find that it shows a figure rather higher than it should.

**Step 3:** leave it for a few minutes to allow the circuit to stabilise, then adjust the 'Intercept' trimpot (VR2) carefully using a small screwdriver or alignment tool to reduce the reading down to the lowest figure you can – ideally –76dBV or less, corresponding to about 0.160mV (160µV) and –73.8dBm.

**Step 4:** remove the 50Ω termination plug from CON2 and instead connect the output of your audio generator. The latter should be set to some convenient frequency (say 1kHz) and to a known audio level – say 1.00V.

**Step 5:** adjust the 'Slope' trimpot (VR1) until you get a reading of +00.0dBV on the LCD.

**Step 6:** reduce the generator output to 10mV and check the dBV reading on the LCD again. It should now read –40dBV, and if you press the unit's Range Select button (S1) so that the micro switches down to the <–20dBV range (ie, orange LED glowing), this reading should remain very close to –40dBV.

In fact, if you press S1 again to switch down to the <–40dBV range (red LED glowing), the reading should still remain very close to –40dBV. If it changes up or down by a significant amount, you should try adjusting either the Intercept or Slope trimpots (or both) very carefully to bring it back to the correct reading.

**Step 7:** to make sure that you have found the correct settings for the two trimpots, try changing the generator output back to 1.00V and also press S1 again to switch the meter back to its top range (<0dBV, green LED glowing). The LCD reading should again be 0.00dBV, but if it has changed slightly you'll need to tweak VR1 and/or VR2 again to bring it back.

The basic idea is to repeat this process a few times until the millivoltmeter is giving the correct readings for both of the known audio levels: 00.0dBV for 1.00V input and –40.0dBV for 10.0mV input. Once this is done, your Digital Audio Millivoltmeter is calibrated and ready for use.

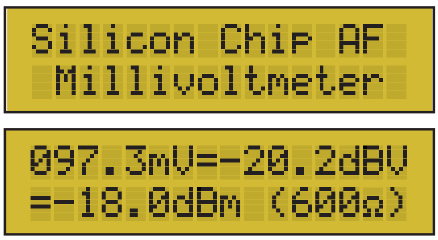
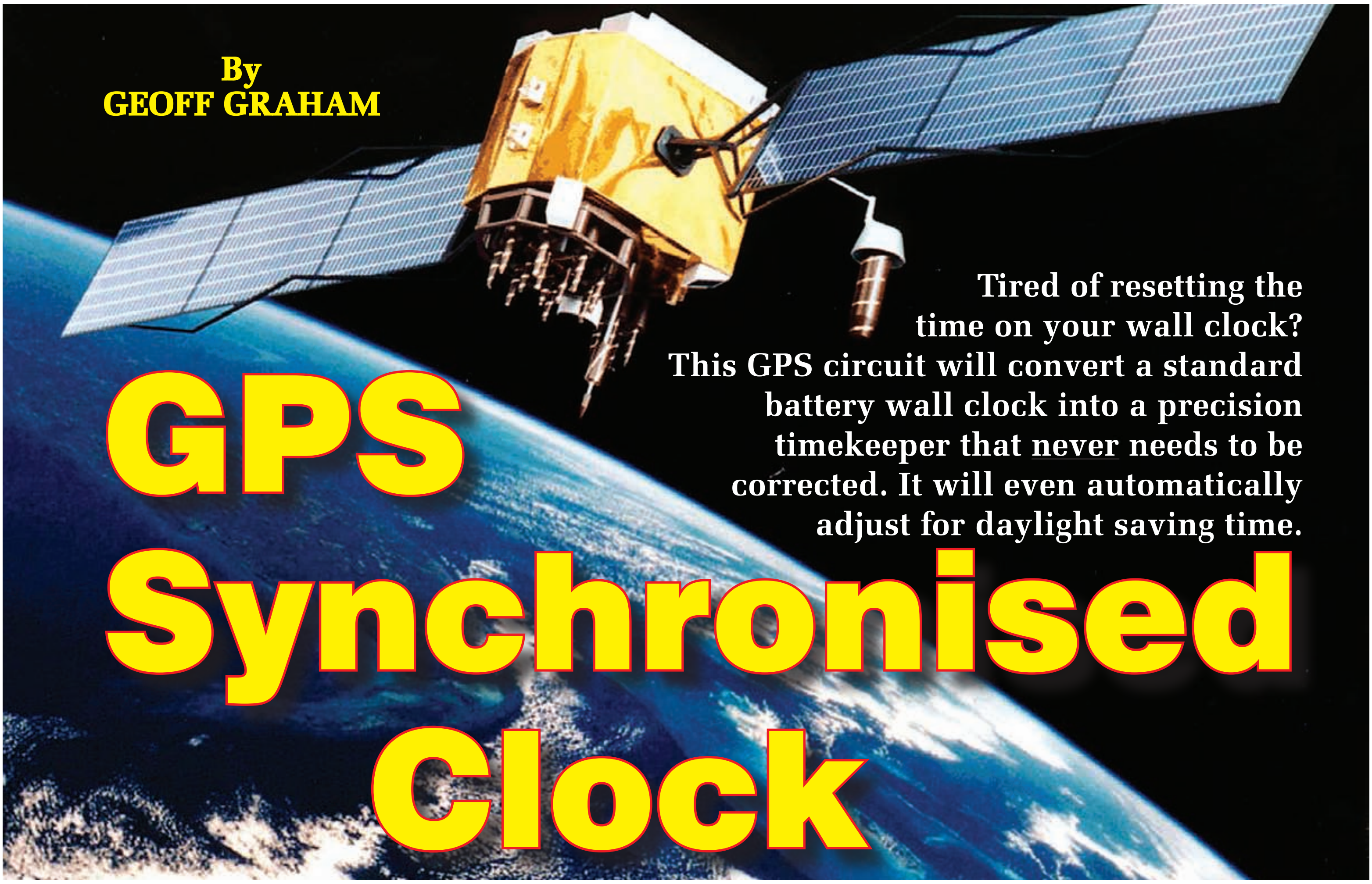



**Fig.9: the display at top shows the message that appears on the LCD when the unit is switched on, while directly above is a typical readout.**

By the way, the maximum audio level that the Audio Millivoltmeter can measure by itself is 1.4V RMS, corresponding to +3.0dBV or +5.2dBm. To use it to make measurements of higher audio voltages, you'll need to connect an audio attenuator/divider ahead of its input.

If there's enough interest, we'll describe such an add-on divider in a future edition of the magazine ***EPE***.



By
GEOFF GRAHAM

# GPS Synchronised Clock

**Tired of resetting the time on your wall clock? This GPS circuit will convert a standard battery wall clock into a precision timekeeper that never needs to be corrected. It will even automatically adjust for daylight saving time.**

BATTERY-POWERED quartz crystal clocks are very common and they keep good time, with a typical accuracy of two seconds per day. However, that couple of seconds can add up. After a month it could be a minute out and after a few months, you are up on a chair again to reset it to the correct time.

Wouldn't it be nice if you never, ever had to do that again?

## GPS time

This design replaces the electronics in a standard quartz wall clock with a controller that synchronises itself via the GPS (Global Positioning Satellite) system. It uses a relatively inexpensive GPS module to get the precise time, and a microcontroller to control the hands of the clock. It will run for about a year on two alkaline AA batteries, and over that period will keep the time accurate to within a few seconds.

Even better, it understands the rules of daylight saving (DST) and will automatically adjust by skipping forward an hour at the legislated time and date when daylight saving starts. When daylight saving stops, the clock will stop for exactly an hour at 3.00am, – and start again when the indicated time is correct.

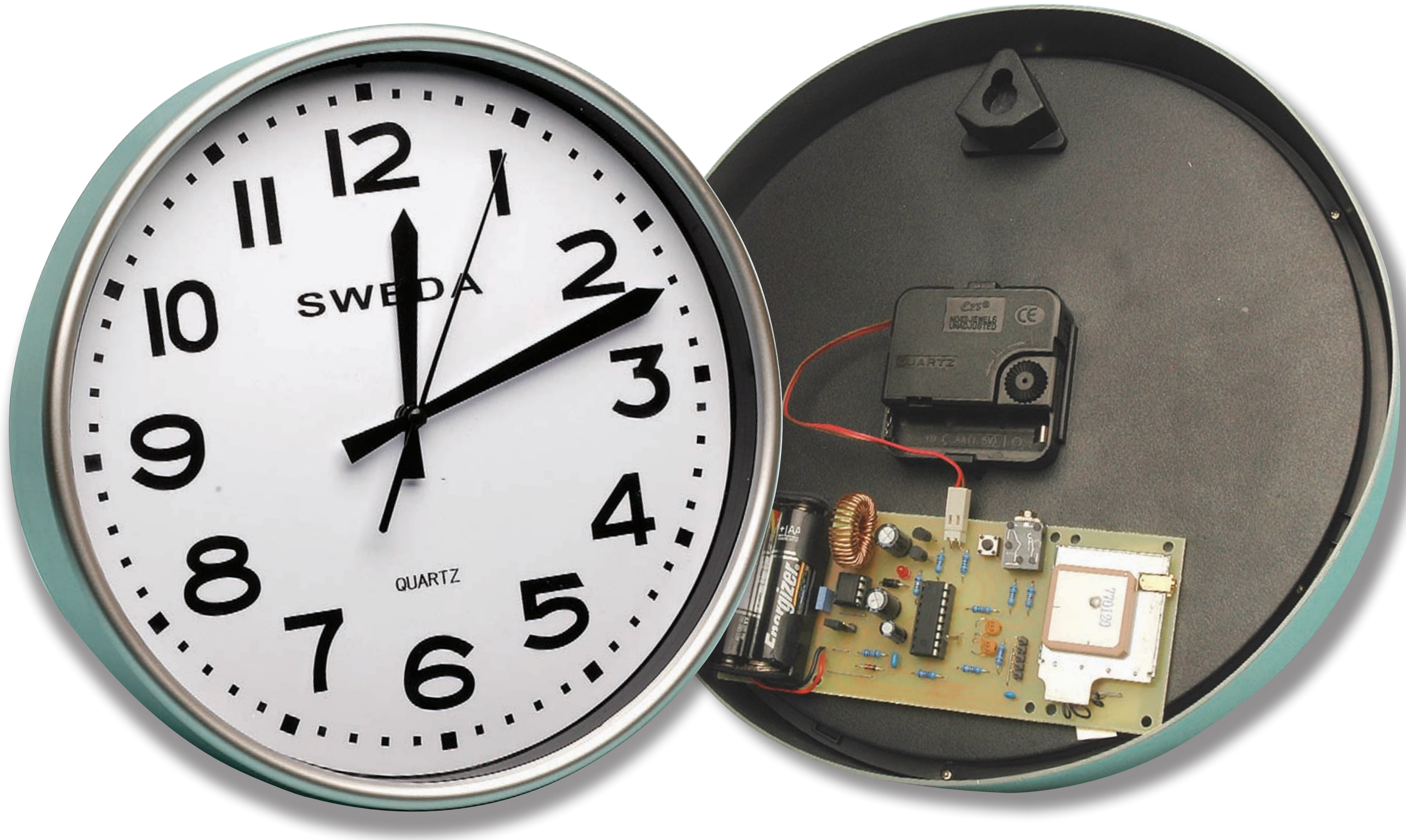
It is also easy to use. All you need to do is set the hands of the clock (including the seconds hand) to the 12 o'clock position and then insert the battery. The controller will use the GPS to get the current time and then step the clock hands at double speed around the dial until it has reached the correct time. It will then drop back into normal timekeeping mode with the time derived from a crystal oscillator.

To conserve the battery, the GPS module is only used to synchronise the clock every 44 hours, and following synchronisation, the clock will either skip seconds or double-step to reach the correct time. After synchronisation, the microcontroller is also able to calculate the inherent inaccuracy of its crystal oscillator and will compensate by occasionally skipping or double-stepping a second. This process can also compensate for ageing of the crystal and will keep the clock accurate between synchronisations.

The controller also monitors the battery voltage and when it has dropped below 2V, the microcontroller will stop the clock at exactly 12 o'clock. You then replace the battery and it will repeat the start-up process by stepping to the correct time. In short, you never have to set the time.

## How it works

First of all, let's look at a standard battery-operated wall clock. It uses a crystal oscillator and a divider to generate a pulse every second to drive a simple stepper motor and, via gears, the hands of the clock. The crystal oscillator is normally quite accurate, especially when new – but it's affected by age, by temperature, by battery voltage . . . all of which can add up to a few seconds a week.




**It looks just like a bog-standard battery-powered wall clock, and in fact, it started out life as such. But it's only when you turn it over . . .**

**You can see it has something that's not bog standard – a GPS module, microprocessor and driver. And no, we haven't forgotten to put the clock movement battery in!**

Our circuit replaces the clock's electronics and generates compatible pulses to drive the stepper motor.

The heart of our controller is a PIC16LF88 microcontroller, which uses a 32.768kHz watch crystal to drive a timer within the chip. This timer generates an interrupt which is used by the software running on the microcontroller to keep time. The software is where all the hard work is done and it is quite complex. As an illustration of this complexity, drafting the circuit of the GPS Clock took just a few hours, while the software took many weeks to develop.

## Clock cycle

A normal clock cycle starts at the beginning of a new second. The timer will generate an interrupt which causes the processor (CPU) in the microcontroller to wake up and execute the interrupt code. The program will perform some calculations (more on this later) and then raise the voltage on one of the clock lines. It then sets the timer to generate another interrupt exactly 40ms after the first interrupt (you can change this) and promptly puts itself back to sleep.

After 40ms, the timer will wake the CPU again and the program will lower the voltage on the clock line, terminating the pulse to the clock's stepper motor. The program then will set the timer to 960ms and go back to sleep. This repeats, second after second.

During the sleep period, everything except the crystal oscillator and the timer is shut down, resulting in a current drain of only a few microamps drawn by the microcontroller. In addition, the CPU in the microcontroller will run at full speed for only 60µs to 100µs while processing an interrupt, so the total current drawn by the microcontroller is negligible. Most of the current, in fact, is drawn by the clock stepper motor – which is the case with a 'standard' battery-operated clock (see the box: Calculating Battery Life).

At the start of a new second, the program compares where the clock hands are actually positioned and where we would like them to be. The software does this with two variables, which hold the current position of the clock's hands in seconds and the desired position. Depending on the result of this comparison, the program will bring the clock's hands closer in agreement to the correct time by skipping a pulse to the clock's stepper motor or by generating a double-step.

Normally, the variable representing the desired position is simply incremented every second, but the beauty of this arrangement is that we can control the position of the clock's hands just by changing this variable. The code within the interrupt routine will automatically bring the hands of the clock into agreement. This is useful when, for example, daylight saving starts – we simply add 3600 seconds (one hour) to the desired position and the clock will fast forward until it is an hour ahead.

When it is time to synchronise, the program will keep running after an interrupt (ie, it will not return to sleep). It then applies power to the GPS module and waits for the GPS to return an

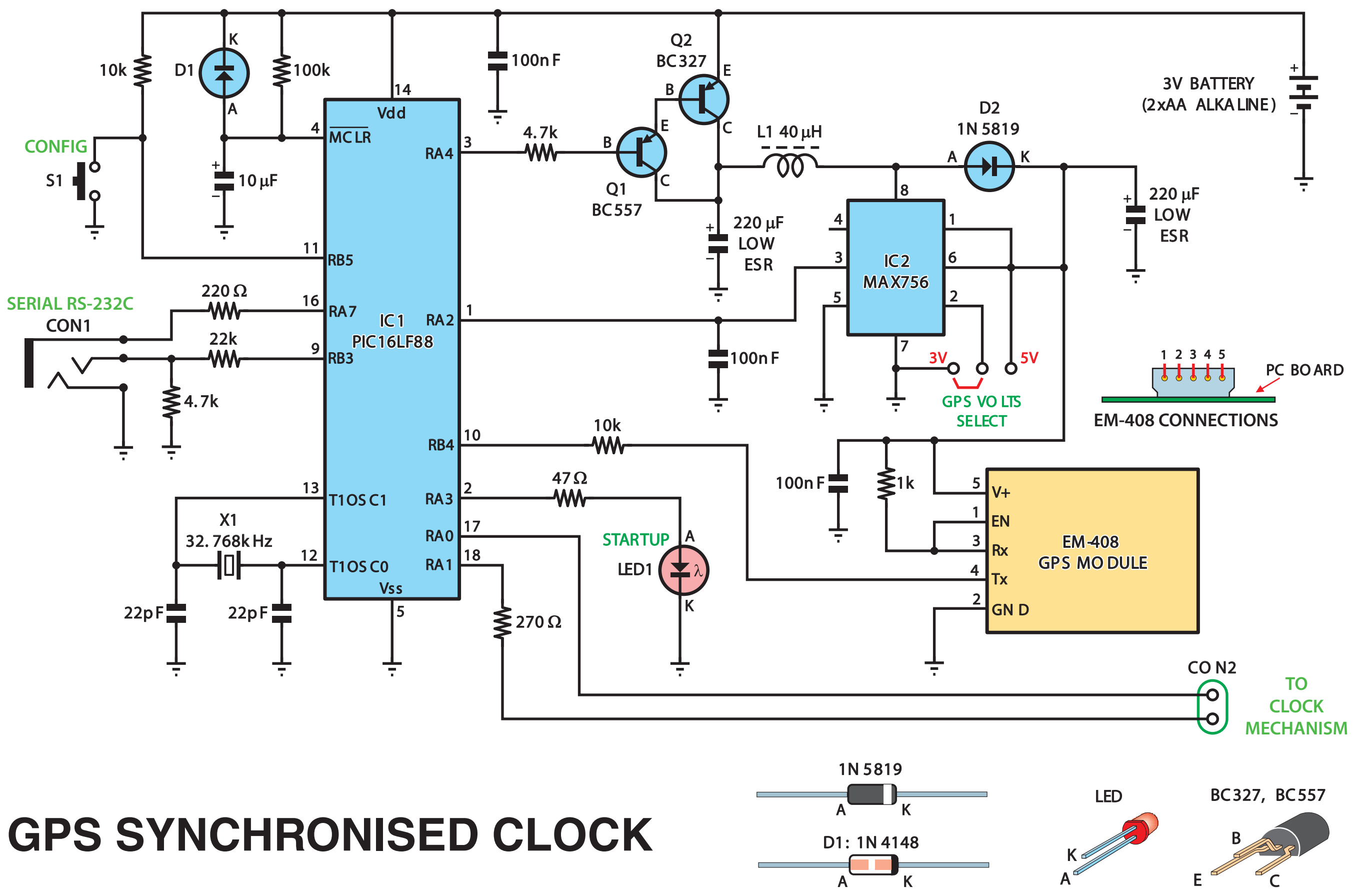



**Fig.1: while it looks very simple (and construction-wise, it is!) there's a lot going on in this circuit, especially in the PIC microcontroller. Full operation is explained in the text.**

accurate time reading. With this reading, the microcontroller has some hard work to do – it must convert it into an internal representation (seconds since 1 January 2000), apply the time zone offset, calculate if daylight saving applies, calculate the internal crystal oscillator error, and more.

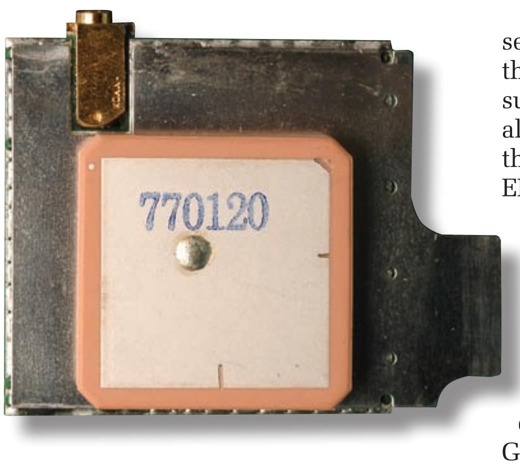
When it is finished, the program will copy the correct time into the variable representing the desired position for the clock's hands and put the CPU to sleep, ready for the next second.

## The GPS module

We normally think of a GPS module as a device to find our position on the globe. However, the GPS system is based on time signals derived from an extremely accurate atomic clock, and as part of their output, they also give the time and date based on that clock.

In fact, most time standard bodies around the world use the GPS system as a 'standard beacon' to transfer accurate clock readings between each other. If you think that it is a waste to discard the latitude and longitude data, as we do with this circuit, then pretend that the module is merely an atomic clock receiver at a cheap price!

Most GPS modules follow the NMEA standard for data output, and generate a serial data stream at 4800 baud with eight bits per character.




**The GlobalSat EM-408 GPS module used in this project. Other modules *may* work fine but we know this one *does*!**

The voltage is inverted with respect to RS232 and uses TTL voltage levels, but otherwise it is the same serial data standard used by desktop computers. The NMEA standard also describes the content of the data and we use the RMC (Recommended Minimum data) message, which is the default for almost every GPS module made.

Finally, the PC board allows you to set the voltage (via a jumper) to power the GPS module (3.3V or 5V). As a result, the clock controller will work with almost any GPS module. Regardless of this, we recommend that you use the EM-408 module produced by Global-Sat in China. It includes everything (antenna and data connector), it is available from many suppliers on the internet (see the parts list), it is relatively cheap and most importantly, we know that it works.

The EM-408 uses the SiRF StarIII chipset, one of the most sensitive GPS chipsets on the market. So, if your normal GPS receiver can work where you intend to place your clock, this will also work.

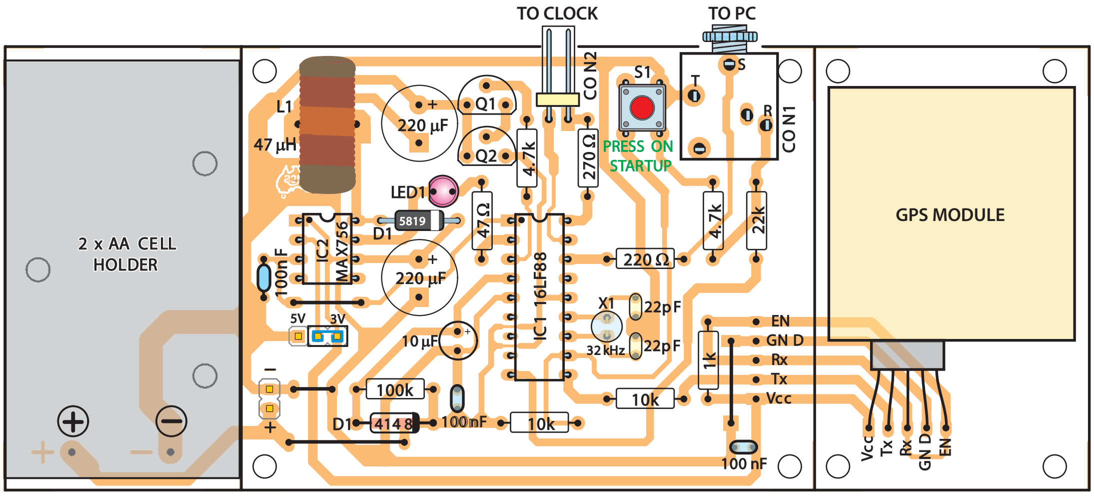
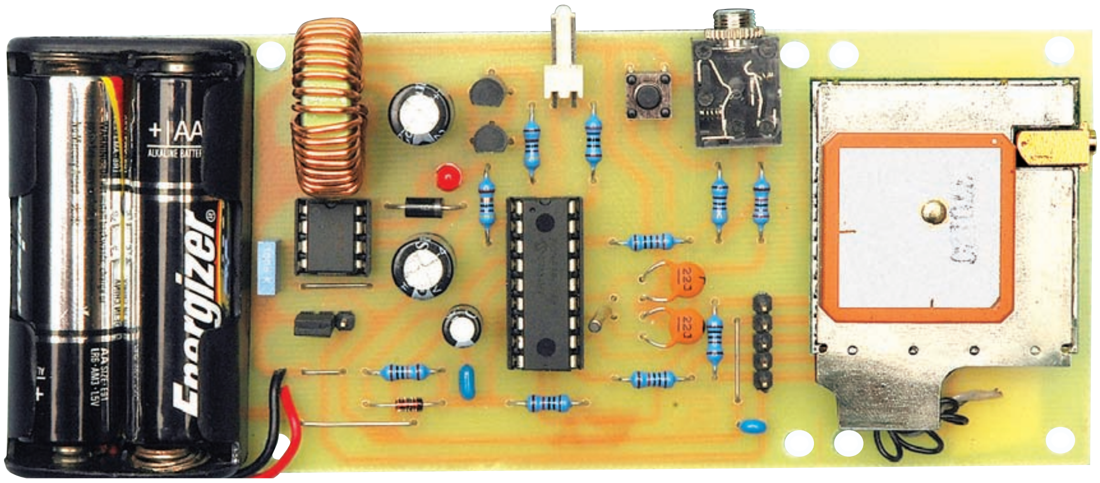



**Fig.2: the component overlay for the GPS Synchronised Clock controller board, along with matching photograph below. Not shown here, but mentioned in the text, is the fact that an IC socket should be used for the microcontroller (IC1) but should NOT be used for IC2 due to the currents involved. The two AA cells on the left side of the PC board should last for at least a year in this application.**



## Circuit description

The full circuit diagram for the GPS Synchronised Clock is shown in Fig.1. The key component is IC1, a PIC16LF88 microcontroller. This drives the clock's stepper motor, controls the power to the GPS module and interprets the output of the module.

The specified chip (with LF in the middle) is the wide voltage version of this common microcontroller, and is guaranteed to operate down to 2V, whereas the standard chip (PIC16F88) is only guaranteed down to 4V.

Having said that, you will probably find that a standard PIC16F88 will operate without fault to below 2V. So, if you have a PIC16F88 in your parts box, give it a go before hunting for the LF version.

The 100kΩ resistor and 10µF capacitor connected to pin 4 of IC1 serve to hold the microcontroller in reset for about a second after the batteries have been inserted. This provides enough time for you to properly seat the batteries in the battery holder before the microcontroller starts executing its program. Diode D1 prevents the capacitor from discharging into the microcontroller when the batteries are removed.

The serial interface connector CON1 is linked to the microcontroller via a few protective resistors. This design relies on the fact that nearly all modern serial RS232 interfaces use a threshold of about 1.5V between a high and low signal. This is not what the full RS232 standard specifies, but we use this fact to provide a simple interface to a personal computer for configuring the clock.

Crystal X1 provides a stable timebase for the clock, with the two 22pF capacitors providing the correct loading. Normally, the accuracy of the clock between GPS synchronisations would be dependent on trimming these capacitors to achieve a frequency of exactly 32.768kHz, but as the software automatically corrects for any errors, this is not required.

The microcontroller applies power to the GPS module by pulling its pin 3 low. This turns on the Darlington transistor pair of Q1 and Q2, resulting in about 2.7V (with fresh AA cells) appearing at the collector of Q2.

## DC-DC converter

This voltage is stepped up by IC2, a MAX756 DC-DC converter. IC2 operates by drawing a current through inductor L1 and then suddenly cutting it off. The collapsing magnetic field causes a positive voltage spike across the inductor that is dumped via diode D2 into the 220µF capacitor.

IC2 can operate with a low supply voltage and still deliver a closely regulated output of 3.3V or 5.0V. The actual output voltage is controlled by pin 2, and this can be configured on the PC board to suit the GPS module in use.

Inductor L1 must have a saturation current rating of 1A or greater. This means that it should be wound with heavy gauge wire on a powdered iron core; an RF choke will not work. The parts list provides two alternatives. Also, both the 220µF capacitors must have a low ESR (equivalent series resistance).

Diode D2 is a 1N5819 Schottky type specified for its low voltage drop. Don't be tempted to substitute an ordinary silicon diode, because its higher voltage drop will lower the efficiency of the DC-DC converter and limit its operation at low battery voltages.

Note that with a minimum battery voltage of 2V and a 0.7V drop through Q2, the voltage delivered to IC2 can be as low as 1.3V. The MAX756 has a typical minimum

## Calculating Battery Life

With an application such as this, battery life is important. After all, what is the point of a clock that does not need adjustment if you are forever changing the batteries?

To calculate the battery consumption, we need to divide the activity of the circuit into phases according to the current drawn from the battery.

Then, for each phase, we determine the current consumption and its duty cycle (the percentage of time that the current is drawn).

Finally, we can calculate the average current drawn per hour and then the battery lifetime for a given capacity of battery. The table below is the result for our prototype.

This table clearly indicates what is the major power user and this is the current drawn while driving the clock's stepper motor. This is where you should concentrate your efforts if you wish to improve the battery life.

One way to do this is to reduce the width of the pulse using the set-up menu. Another option would be to increase the value of the 270Ω resistor which limits the current drawn by the clock's stepper motor.

If you experiment with either of these options you should connect a variable power supply in place of the batteries and test that your clock steps correctly at less than 2V, the minimum expected battery voltage.

Don't just test it on its back either; stand the clock upright in its normal position because you might find that the stepper motor does not have enough power to lift the second hand against gravity.

| Function | Current Draw (mA) | On Time (seconds) | Total Time (seconds) | Duty Cycle | Consumption (mA hour) |
|---|---|---|---|---|---|
| PIC in sleep | 0.004 | 158355 | 158400 | 99.97% | 0.004 |
| Clock step pulse | 6 | 0.04 | 1 | 4.00% | 0.240 |
| During GPS synch | 80 | 45 | 158400 | 0.03% | 0.023 |
| Battery self discharge* | 0.009 | 1 | 1 | 100.00% | 0.009 |
| | | | | TOTAL DRAIN (mA hours) | 0.276 |

Lifetime for alkaline AA cells (capacity of 2400 mA hours*) in months 12.1

* source: Energiser Alkaline Handbook Alk1.1

start-up voltage of 1.1V, so normally it should be OK.

However, the specs for the MAX756 say that this might be as high as 1.8V on some devices. So, if you get one of these chips, you might find that the clock will shutdown (stop at 12 o'clock) before the battery drops to 2V. This is unlikely, but the only solution is to try a few different chips. All our samples worked without fault.

IC2 generates a reference voltage of 1.25V, which is used in regulating its output voltage. This reference voltage is also made available at pin 3 of the chip, and we pass it back to the microcontroller which uses it as a reference to measure the battery voltage. By accurately measuring the battery voltage, we can stop the clock at the 12 o'clock position before the batteries get too low to operate the microcontroller.

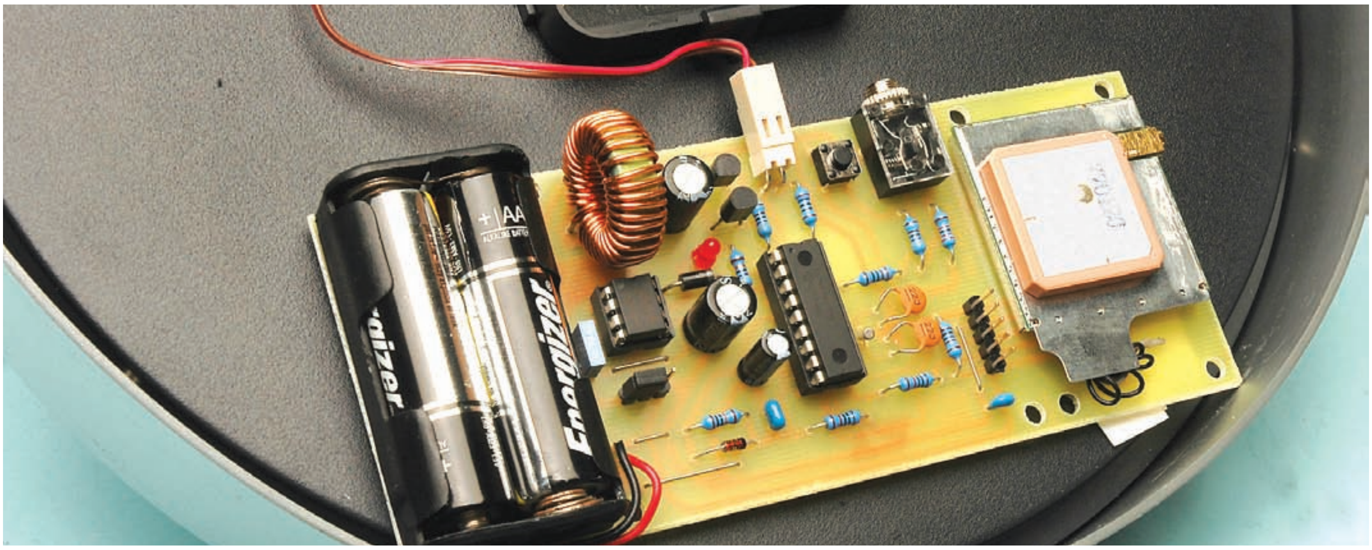
Incidentally, the microcontroller is programmed to measure the battery voltage at the time of greatest current draw (about 160mA) when the GPS module is starting up. If you measure the battery voltage without a load, you will probably get a higher reading.

The GPS module is one of the simpler parts of the circuit. It has two connections for power, two for communications to the microcontroller (transmit and receive data) and an enable signal. We pull the enable line high with a 1kΩ resistor so that the module is always enabled when power is applied.

As we do not send anything to the GPS module (the manufacturer's default configuration suits us just fine), the receive data line is also pulled high by the same 1kΩ resistor. The 10kΩ resistor on pin 10 of the microcontroller limits the current into the microcontroller when the GPS module operates at a higher voltage.

The microcontroller drives the clock stepper motor from pins 17 and 18. The 270Ω resistor limits the current so that the coil of the stepper motor sees about 1.5V, which is the normal supply for this type of clock.

The clock pulses alternate so that the first clock pulse is delivered by momentarily raising pin 17 high while pin 18 is held low – this will step the




**There is usually plenty of room (assuming the clock is large enough) to fit the PC board, which includes the dual AA battery holder and the GPS module. It can be held in place with some double-sided adhesive foam pads.**

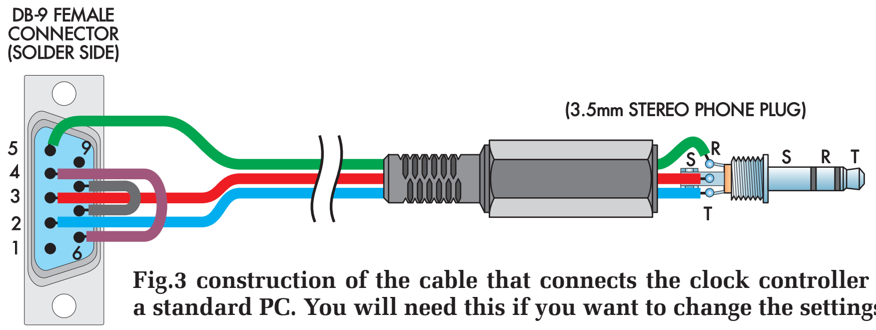



**Fig.3 construction of the cable that connects the clock controller to a standard PC. You will need this if you want to change the settings.**

clock's hands by one second. For the next second this is reversed, and pin 18 is taken high while pin 17 is held low. This cycle is repeated to drive the clock's hands around the dial.

## Construction

All of the components for the GPS Clock, including the GPS module and the AA cell holder, are mounted on a PC board measuring 140mm × 57mm and coded 793. This board is available from the *EPE PCB Service*. The component overlay diagram is shown in Fig.2.

Check the board carefully for etching defects, shorted copper tracks or undrilled holes. Then install the four wire links on the board and continue with the low profile components, moving up to the transistors and capacitors. When mounting the battery holder, use double-sided adhesive tape or put a dab of glue on its underside before soldering it in. This will hold it securely when you remove or replace the batteries.

IC2 *must* be soldered directly to the printed circuit board. Do not use an IC socket as the switching current through L1 is quite high and the voltage drop through the socket contacts will prevent IC2 from working correctly at low battery voltages.

On the other hand, you should use a socket for IC1 so that you can remove it for reprogramming. The PIC16LF88 (IC1) must be programmed with the file GPS Clock .hex which will be available from the *EPE* website.

## GPS cable

The GPS module comes with a connector cable with identical connectors at each end. We only need one, so cut the cable in the centre. This will give you two separate cables, each with a connector.

On one of these cables you should bare the cut ends and solder them to the PC board, ready for the GPS module. The other cable can be used if you need to unplug the GPS module from the board and test with your computer (see box: Experimenting With The GPS Module).

Solder in the 3-pin header for LK1. Then install the jumper to select 3V for the GPS module. This must be done *before* the board is powered up.

```
GPS Clock firmware 1.1

 1 = Set timezone (hrs)                    (now +10.0)
 2 = Set daylight saving off               (now on)

 3 = Set start daylight saving month       (now 10)
 4 = Set start daylight saving Sunday      (now 1)
 5 = Set end daylight saving month         (now 4)
 6 = Set end daylight saving Sunday        (now 1)

 7 = Set clock pulse (msec)                (now 40)
 8 = Set GPS update (hrs)                  (now 44)

 Q = Quit

Command:
```

**The setup menu is self-explanatory and provides prompts to help you. You can use it to set the clock to operate anywhere in the world.**

## Parts List – GPS Synchronised Clock

- 1 PC board, code 793, available from the *EPE PCB Service, size* 140mm × 57mm
- *1 GlobalSat Technology EM-408 GPS module
- 1 32.768kHz crystal (X1)
- 1 47µH high saturation inductor (Jaycar LF1274)
- 1 3.5mm stereo phono socket
- 1 momentary 'click effect' push-button switch
- 1 dual AA battery holder
- 1 18-pin IC socket
- 1 2-way header plug, 2.54mm pitch
- 1 2-way header socket, 2.54mm pitch, PC-mount, 90° pins
- 2 AA alkaline cells

**Semiconductors**
- 1 PIC16LF88-I/P microcontroller programmed with GPS Clock .hex (IC1)
- 1 MAX756CPA DC-DC Converter (IC2). Available from: **www.futurlec.com**
- 1 BC557 *PNP* transistor (Q1)
- 1 BC327 *PNP* transistor (Q2)
- 1 1N4148 diode (D1)
- 1 1N5819 Schottky diode (D2)
- 1 3mm red LED (LED1)

**Capacitors**
- 2 220µF 25V low ESR electrolytic (Jaycar RE6324)
- 1 10µF 16V electrolytic
- 3 100nF monolithic
- 2 22pF ceramic

**Resistors** (0.25W 5%)

| | | |
|---|---|---|
| 1 100kΩ | 1 22kΩ | 2 10kΩ |
| 2 4.7kΩ | 1 1kΩ | 1 270Ω |
| 1 220Ω | 1 47Ω | |

*** The EM-408 GPS module specified suits the PC board pattern and also has an integral antenna.It is available from: www.sparkfun.com part number GPS-08234, or www.starliteintl.com or www.coolcomponents.co.uk and other suppliers).**
**Other modules may have different spacing and require an external antenna.**

If you don't do this, pin 2 of IC2 will float and might cause the IC to deliver a 'lethal' voltage to your GPS module.

## Powering up

Before you plug in the GPS module, you need to make some tests. With IC1 plugged into its socket, insert two fresh batteries in the battery holder. After a second you should see one flash from the Startup LED, followed by a further two flashes another second or so later. These indicate that the microcontroller and the DC-DC converter, respectively, are working. If you do not get these indications you should refer to the section on troubleshooting below.

After the double flash, the microcontroller will wait for two minutes, expecting some data from the GPS module before shutting down the DC-DC converter. In this time, you need to measure the voltage at the connector to the GPS module. It should be between 3.2V and 3.5V, which is the safe range for the module. To reliably measure the voltage you need a load for the DC-DC converter, so connect a resistor of about 330Ω across your multimeter leads.

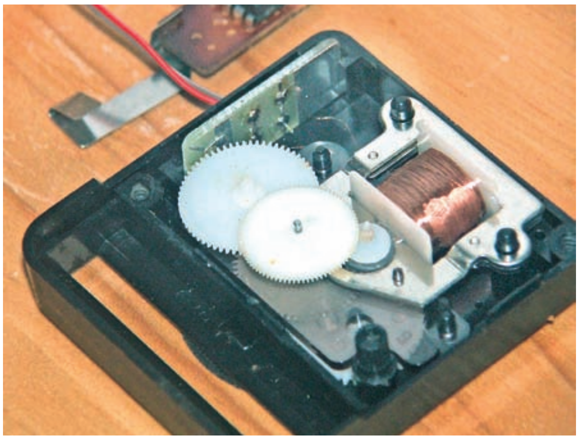
Now that you have confirmed that you will not blow up your GPS module you can remove the batteries and plug in the GPS module. The module should be attached to the PC board using double-sided adhesive tape.

Finally, replace the batteries and the controller should go through the whole startup sequence as described in the section on troubleshooting.

## Modifying the clock mechanism

Jim Rowe's article in the October 2009 issue of *EPE* provided a good description of the modifications required to access a clock's stepper motor. You will have to remove the cover from the clock mechanism, identify the leads to the stepper motor coil, cut and terminate these somewhere, and finally connect them to a lead terminated with a 2-way header plug. The stepper motor coil should be easily identified, as it will be a large coil of enamelled copper wire. Every clock is different, so you will be on a journey of discovery here.

You can check your modification by using a 1.5V battery. Just connect the battery to the wires leading to the stepper motor coil, then reverse the battery and repeat. On each connection, the clock's second hand should step by one second.



**The insides of a typical quartz clock mechanism showing the modifications we made to terminate the connecting leads to the stepper motor coil.**

The method of attaching the PC board to your clock will also vary, but in the simplest case, you can use double-sided adhesive tape to hold it onto the back of the clock. The board has been designed so that you can cut off the area holding the batteries or the area holding the GPS module, or both. This might come in useful if you need to squeeze it into a small space.

Note that this design will only work with the standard type of quartz clock that 'ticks' every second. Some modern clocks with a sweep second hand employ a different drive mechanism and will not work with this controller.

## Troubleshooting

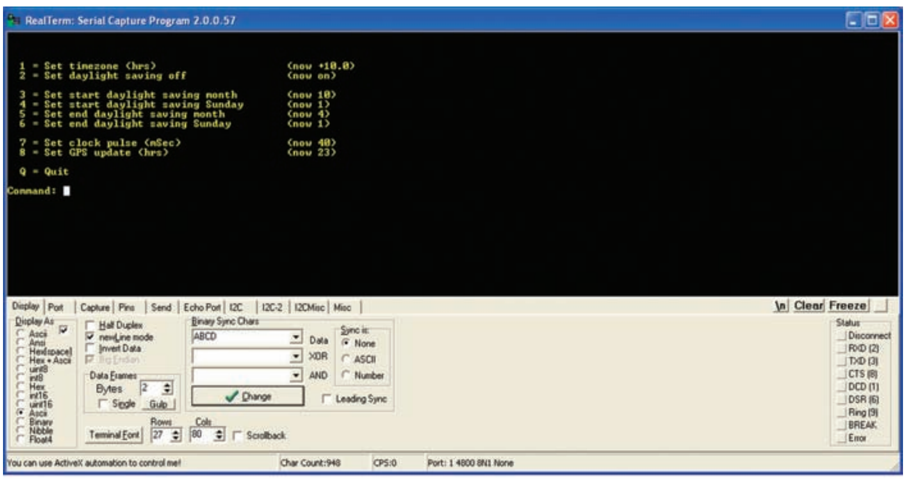
Hopefully your clock will work first time, but if it does not, you can use the Startup LED to help isolate the problem. This LED will flash during normal initialisation (when the set-up button is not pressed) to indicate that each step of the initialisation has been completed. The point at which it does not flash will indicate where you should start hunting. When you insert the batteries you should see the following signals in sequence:

**One flash:** the microcontroller has started up. If you do not get this then something is fundamentally wrong with the microcontroller or the batteries.

**Two flashes:** the MAX756 DC-DC converter has started up (determined by measuring a voltage on pin 3 of IC2). If you fail to get this signal you should check IC2 and its associated components. Check for approx 2.7V (with fresh batteries) on the collector of Q2 and between 1.23V and 1.27V on pin 3 of IC2.

**Three flashes:** the GPS module is working and has transmitted its startup message. If you do not get this then check the wiring to the module. The GPS module is very sensitive to its power supply. Check that this is between 3.2V and 3.5V. If you have an oscilloscope, check that there is less than 150mV peak-to-peak noise superimposed on the supply rail to the GPS module.

**Four flashes:** the GPS module has locked on to sufficient satellites and has responded with an accurate time signal. This can take up to 90 seconds or more, so be patient.




**You will need a PC terminal emulation program to change the clock controller's settings. Many free programs are available for download on the Internet.**

Immediately following the GPS lock (four flashes), the clock should double-step around the dial to reach the correct time. If this does not happen, it means that the crystal oscillator (X1) is not working or the clock's stepper motor is not correctly wired to the controller. In particular, check that you have isolated the clock's electronic module and soldered your wires properly to the stepper motor coil.

Incidentally, to save the clock from having to double-step for hours to reach the correct time, it makes sense to power up the clock shortly after 12 o'clock (ie, your local time). In that way, it will only take about ten minutes or so for the clock to finish double stepping and revert to normal accurate time keeping.

## Experimenting With The GPS Module

If you would like to experiment with the GPS module, you can connect it directly to your personal computer using the circuit below. If you do change the settings of the module, remember to reset it to the manufacturer's default configuration before using it in the clock controller.

Descriptions of the commands accepted by the EM-408 are available on the Internet. Search for 'EM408 User Guide' and 'SiRF NMEA Reference Manual'.

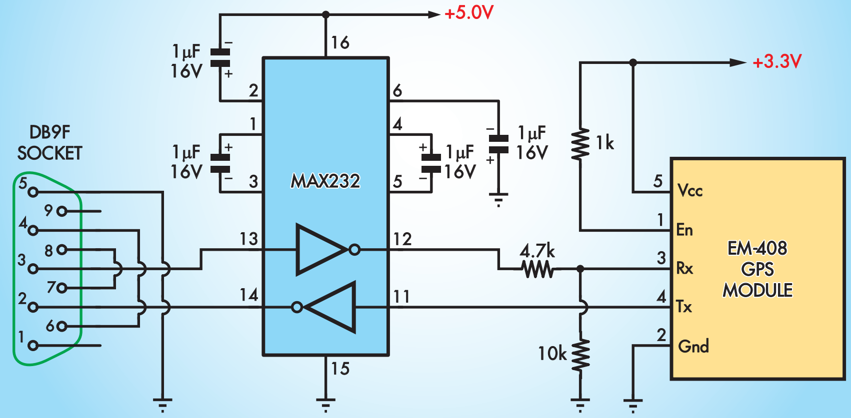



**Fig.4: GPS Module to PC test interface. This can be constructed on a small piece of perforated board, and may be useful if you need to diagnose a fault or reset the module if it becomes stuck in a strange mode.**

## Set-up

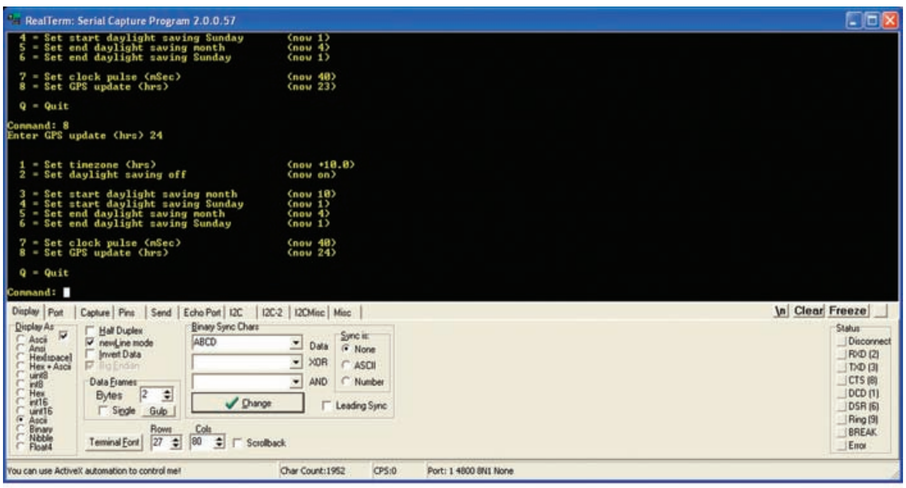
By default, the controller software is configured for the NSW, Victorian and Tasmanian time zone and daylight saving rules. If you live in these states and the government has not changed the daylight saving rules (unlikely), then you do not need to do anything.

If you live elsewhere, you will need to change the settings by connecting the GPS Clock to a serial RS232 port on a personal computer. If your computer does not have a 'legacy' serial port then a USB-to-RS232 converter cable will do fine.

The cable from the clock controller to the PC is the same as the serial download cable used by Revolution Education Ltd for their PICAXE experimenter board, so if your have been programming PICAXEs, you can get double use from it! It is terminated at one end with a stereo phono connector and a 9-pin D connector at the other end – see Fig.3 for details. These cables are available from Microzed **(www.microzed.com).**

You will also need a serial terminal emulation program running on your computer configured for 4800 baud, 8 data bits, no parity and one stop bit. Many free programs are available on the Internet, including PuTTY, RealTerm or Hercules Terminal Emulator. Use Google to search for one or more of these names.

To enter set-up mode, hold down the Set-up button while you install fresh batteries and continue to hold it down until you see the menu. The Startup LED will also flash when the microcontroller transmits a character to your computer, and this may help in diagnosing communication problems.




**It is easy to reconfigure the clock for different time zones and clock mechanisms. When you change a setting you are prompted to enter the correct data.**

If you are observing daylight saving you can select any month for the end or start. You can also set the day for the event (1st, 2nd, 3rd or last Sunday in the month). The time of the day that daylight saving starts (2am) is fixed in the program, as is the end time (3am).

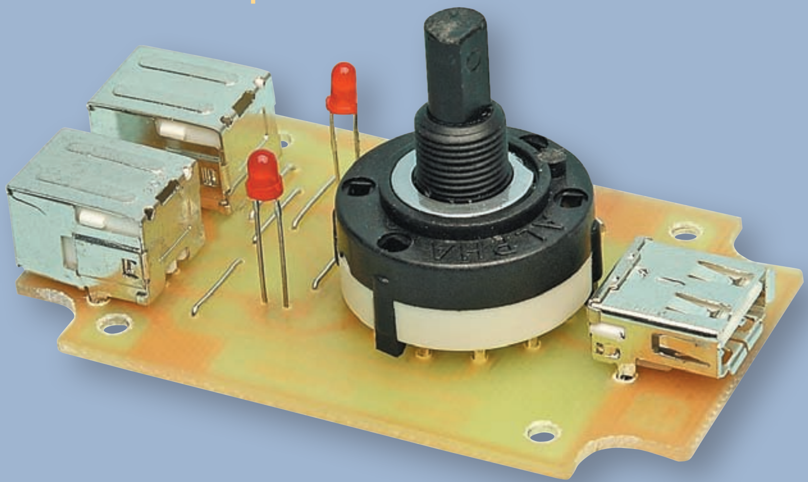
The clock pulse width can be changed in steps of 8ms and this setting might need to be adjusted to suit your clock. Most clocks work with the default 40ms, but some may need 48ms or even 56ms to reliably step with a low battery voltage. Finally, to gain a little extra accuracy or improve battery life you can change the interval between GPS synchronisations.

All changes are saved in non-volatile memory and therefore will be retained, even when you remove the battery.

Well, that's it. With your clock properly set up you can hang it on the wall and be assured that at least one clock in the house is accurate.

Incidentally, you can also check the clock's accuracy at any time if you have Internet time enabled on your desktop computer. ***EPE***

Share a USB printer or other USB device between two PCs




# Manual 2-Way USB Device Switch

**This simple device allows two computers to share a single USB printer or some other USB device, such as an external flash drive, memory card reader or scanner. A rotary switch selects the PC that you wish to use with the USB device, while two LEDs indicate the selected PC.**

**By JIM ROWE and GREG SWAIN**

THE MOST common way to share a USB printer between two PCs is to use one machine as a print server. However, that's not always convenient because it means that the server PC must always be on if you want to print something.

That can be a real nuisance if you just want to quickly fire up the other machine and print something out. It also means that the two PCs must be networked together, either via a hub/router or directly via an ethernet crossover cable.

Another way is to use a dedicated USB print server. However, as before, this must be connected to an ethernet network, along with the PCs. Such devices also need their own power supply, generally cost well over £50 and are overkill if you just want to share a single USB printer between two computers for occasional printing in a home set-up.

That's where this simple device comes in. It's basically a 2-way switch box that lets you manually switch your USB printer from one PC to the other, as required. The switching is performed using a rotary switch, while two LEDs on the front panel indicate which PC has been connected to the printer.

This method has several advantages. First, you don't need to network your two computers. Second, you can print from either machine with the other turned off. And third, the device doesn't need a power supply.

It's also cheap to build and easy to set up – just run standard USB Type A to Type B cables from your PCs to the USB Switch, and connect a third cable from the switch to the printer. That's it.

## Other devices

This device is not simply confined to switching a USB printer – it can also be used to switch other USB devices, such as USB flash drives, memory card readers, USB digital picture frames and scanners. However, if you


## Parts List

1 PC board, code 796, available from the *EPE PCB Service*, 77mm × 46mm
1 UB5-size plastic utility box, 83mm × 54mm × 31mm
1 front panel label, 48mm × 77mm
2 Type B USB sockets, PC-mount (CON1, CON2)
1 Type A USB socket, PC-mount (CON3)
1 PC-mount 4-pole, 3-position rotary switch, with knob to suit
4 M3 × 15mm tapped spacers
4 M3 × 6mm machine screws
4 M3 × 6mm countersink-head machine screws
2 3mm red LED (LEDs1and2)
1 470Ω resistor

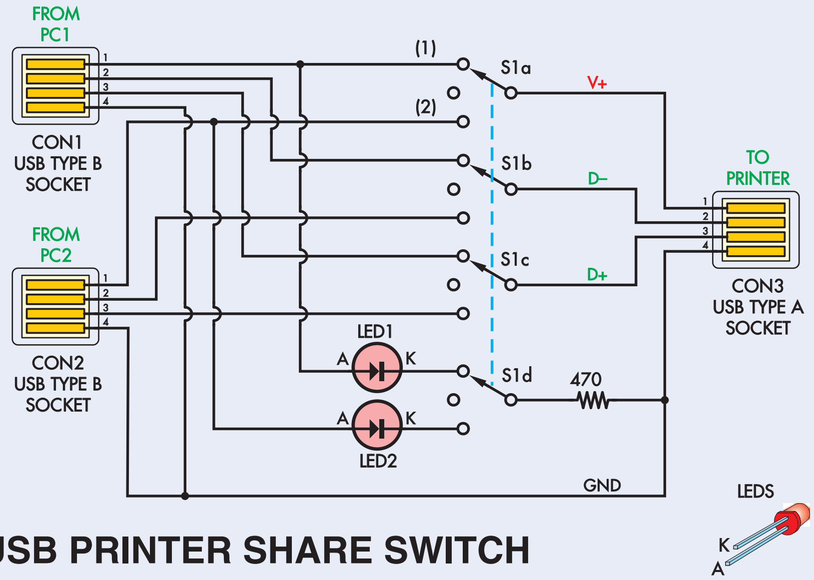



**Fig.1: the circuit uses switch poles S1a to S1c to select either USB socket CON1 or CON2 and connect its pins through to CON3. The fourth pole (S1d) selects either LED1 or LED2, to indicate which PC has been selected.**

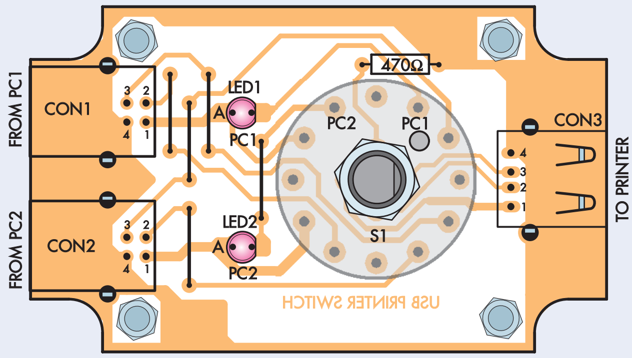



**Fig.2: install the parts on the PC board as shown here. Note particularly the orientation of switch S1. It's mounted so that the flat side of its shaft faces CON3 when the switch is in the centre position.**

are switching a USB flash drive, you must always be sure to go through the 'Safely Remove Hardware' procedure before switching over, otherwise you could lose data.

### Circuit details

Let's take a look at the simple circuit, shown in Fig.1.

There's not much to it. At the left, we have two USB Type B sockets to accept the signals from the two PCs (PC1 and PC2). These are the upstream ports and their V+, D– and D+ (data) lines are connected to switches S1a to S1c respectively, while their GND terminals (pin 4) are commoned and fed through to pin 4 of USB Type A socket CON3.

Basically, S1 is wired as a 4-pole 3-position switch. However, the centre position is unused. That's been done to ensure a clean break when switching between positions 1 and 2 of each pole, so that either a break-before-make or a make-before-break switch can be used.

In operation, S1a to S1c simply select between USB sockets CON1 and CON2. In position (1), the outputs from CON1 are selected and fed through to the downstream USB output socket (CON3). Conversely, in position 2, CON2's outputs are selected and fed through to CON3.

Switch pole S1d selects between LED1 and LED2, to indicate which input socket (and thus which PC) is selected. These two LEDs connect to the V+ (+5V) lines from CON1 and CON2 respectively, while the associated 470Ω resistor to ground provides current limiting (to about 10mA).

As a result, LED1 lights when S1 selects position 1 (CON1), while LED2 lights for position 2 (CON2).

CON3 is a USB Type A socket. This is connected to the USB device (eg, a printer) via a standard USB Type A to Type B cable.

### Construction

All the parts for the USB Switch are mounted on a small PC board coded 796 (see *PCB Service*) and measuring 77mm × 46mm. This assembly fits inside a standard UB5-size plastic utility box, with rectangular cutouts at either end to access the USB sockets.

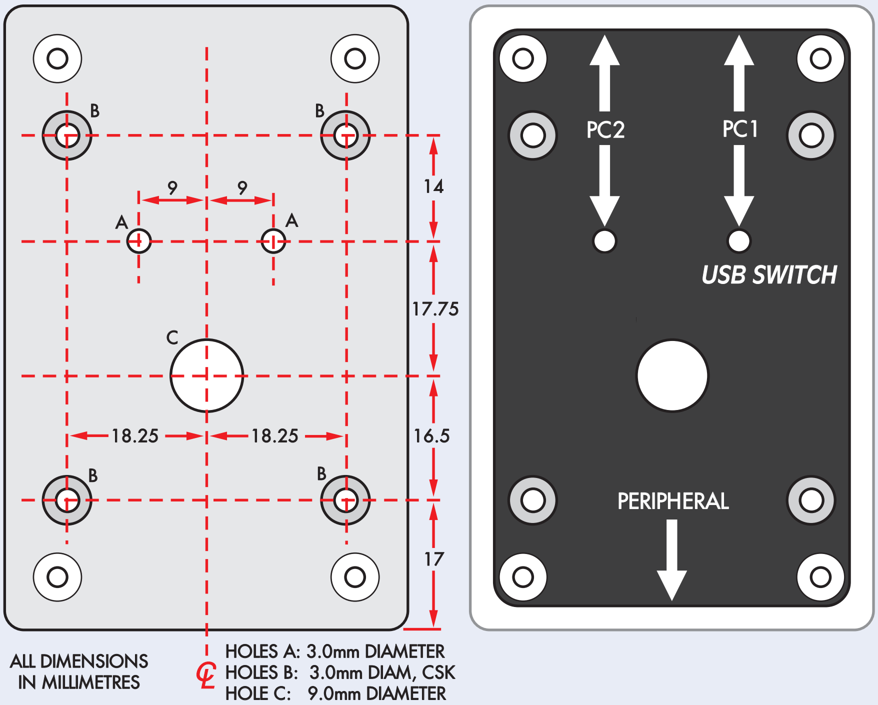
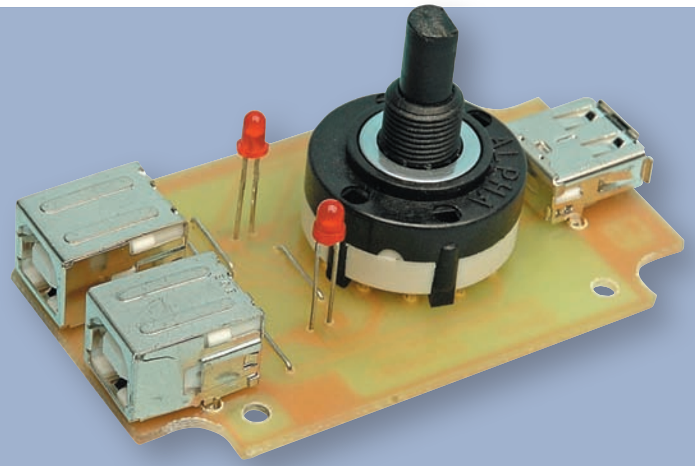
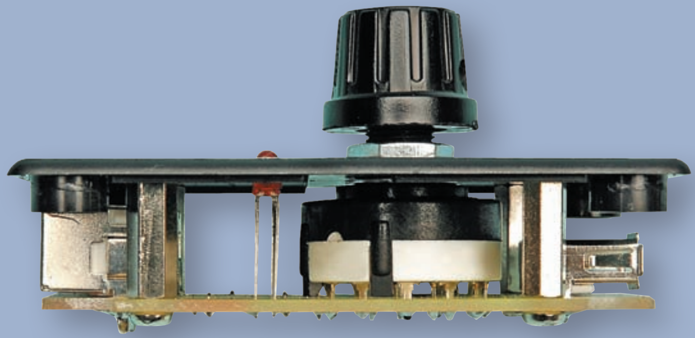



**Fig.3: this diagram shows the drilling and cutout details for the lid (left), together with the full-size front-panel artwork (right).**



**This is the fully-assembled PC board. Be sure to install the rotary switch with the flat side of its shaft towards CON3 (at right) when the switch is in the centre position. The LED leads are soldered after the board has been attached to the lid (see text).**



**The PC board is attached to the lid of the case using four M3 × 15mm tapped spacers and M3 × 6mm machine screws.**

Fig.2 shows the parts layout on the PC board. Begin the assembly by installing the five wire links and the 470Ω resistor. The three USB sockets can then be installed. Make sure these sit flush against the PC board before soldering their pins, and don't forget to solder the large tabs on either side of each socket.

Switch S1 is next. First, cut its shaft to 10mm, then install it on the board so that the flat side of the shaft faces CON3 when the switch is in the centre position. Be sure to push the switch all the way down, so that it sits flush against the board before soldering its pins.

Once the switch is in, fit an M3 × 15mm tapped spacer to each corner mounting position. Secure these using M3 × 6mm screws. The board assembly is then complete except for the two LEDs, which we'll come to shortly.

## Final assembly

Fig.3 shows the drilling details for the case lid. Four 3mm mounting holes are required for the PC board, two 3mm holes for the LEDs and a single 9mm hole for the switch shaft.

Fig.3 also shows the full-size artwork for the front-panel label. This can be photocopied and glued to the lid of the case. But first, protect it by covering it with clear contac film, then attach it to the lid using a thin smear of silicone sealant as the adhesive. Wait until the silicone dries before cutting out the holes using a sharp hobby knife.

The PC board can now be attached to the lid. First, slip the two LEDs into position (check their orientation), then secure the board to the lid using four M3 × 6mm countersink-head screws. That done, fit the switch nut, then push the LEDs through their front-panel holes and solder their leads.

The final step is to make the cutouts in the ends of the case for the USB sockets. You will need two 12 × 10mm cutouts for the type B sockets and a 17 × 9mm cutout for the type A socket. These can be made by first marking out their positions, then drilling a series of holes around the inside perimeters, knocking out the centre pieces and filing them to a neat finish.

That's it – your USB Switch is now complete. Attach the lid to the case, fit the knob and it's ready to go. ***EPE***

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# Max's Cool Beans

By Max The Magnificent

## High definition

DID YOU know that the first public high-definition (HD) TV broadcast in the United States took place as long ago as 1996? At first, there was so little HD content available that having an HD set really wasn't worth it. Even when more and more channels started to provide HD content, I told myself that I was happy with my big old standard-resolution CRT TV. Then, around a year ago, as I blog away, my wife went shopping for something or other and came back with a 46-inch HD TV, which meant that I had to upgrade our satellite TV service to HD (mutter mutter, grumble grumble). Wow! What a difference! I love our new HD TV! Even when playing regular DVDs of old movies like *Meet Me in St. Louis* from 1944 featuring Judy Garland, my wife and I keep on spotting details we never saw before.

Of course, technology continues to race forwards. Consider the fact that current 1080p (two megapixel) HD displays – as wonderful as they are – are already well on their way to becoming obsolete. In the very near-term future we're going to start hearing more and more about next generation TV sets and projectors and suchlike. For example 4K2K (4096 x 2400 pixels = 10 megapixels) followed by 8K4K (7680 x 4320 pixels = 33 megapixels), where this latter version is also known as 'Super Hi-Vision' or 'Ultra HDTV'.

## Not science fiction

What? You think this is science fiction, or at least way in the future? Well, did you know that Japan has announced plans to make 8K4K a broadcast standard by 2015, and the BBC has plans to broadcast the 2012 Olympic games in 8K4K?

AND… in addition to all of this, there's the advent of 3DHDTV. We've all seen 3D films like *Avatar* or *Toy Story 3* at the cinema. Of course, you have to wear special glasses (which is a pain), but the resulting images are really good.

More recently, 3D television sets have started to appear. As far as I know, all of these also currently require you to wear special glasses (which, as we noted, is a pain) … plus the amount of 3D content that is available is still extremely limited, but all of this is set to change. For example, the *Discovery Channel* has committed to start recording everything in 3D in the immediate future, and other channels are sure to follow.

I don't fully understand the technology behind all of this, but I've been told that it won't be long before 3D HD TVs become available that don't require the wearing of special glasses. The great thing is that this doesn't affect the way in which the digital content is recorded *per se* – so long as you have two stereoscopic digital video streams, it will be up to the various 3D display technologies to render these streams as they wish.

But wait, there's more, because I recently discovered that there are 3D cameras and display devices that are available today. Take a look at the amazingly cool Aiptek 3D-HD High Definition 3D Camcorder, which is available from **Amazon.com** for 199.99 US dollars.

This little beauty takes still images or videos. On the front are two cameras, each with a resolution of 640 × 720 pixels. Combined, this gives a resolution of 1280 × 720, which is why this camera is said to be high-definition (HD). To be honest, I think I would really class 1080 × 720 (or higher) for each camera as being HD … but maybe that's really just quibbling on my part (what do you think?).


*Aiptek 3D-HD 3D camcorder*

On the back, there's a 2.4-inch LCD preview screen that utilises what the manufacturer refers to as 'Parallax Barrier Technology' to provide a 3D display without the need for any special. You can watch footage in 3D live as you record it, and also use the LCD for instant 3D playback.

There's even more, because there is also an associated digital picture frame with an 8-inch LCD screen that displays photos and videos in 3D. This is the Aiptek Portable 3D Photo and Video Display, which is also available from **Amazon.com** for 179 US Dollars.

The point of all this is that I think 3D really is going to be the wave of the future. It won't be long before every cell-phone and similar gadget will be able to take photos and videos in 3D, and every display device – like your computer and TV – will be able to present these images without the need for special glasses.

I think all of this is going to happen much faster than you might think. Just this morning, for example, I opened a magazine and saw an article about the forthcoming Nintendo 3DS dual-screen handheld gaming device that will have 3D graphics with no special glasses required. Wow! We truly do live in exciting times.

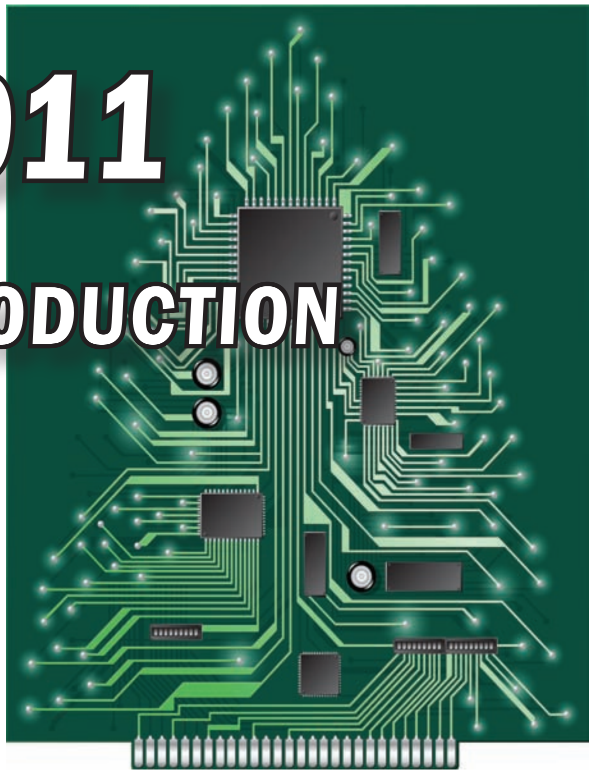
## 3D is for me!

As you may recall, in my last column I mentioned the Optima PK301 Pico Projector, which is an image/video projector that you can drive from your computer (or smartphone or whatever) and that's small enough to fit in the palm of your hand. At that time I promised to report back when I got a chance to play with it. Well, I did get to play with it and I am very impressed. The PK301 obviously isn't as powerful as a larger projector, so you do have to dim the room lights to use it, but the resulting image is still very reasonable.

All-in-all, I have to say that the PK301 is a very tasty little unit that will be a lot of use when I'm giving seminars to small groups of people. Until next time, have a good one!

**Check out 'The Cool Beans Blog' at www.epemag.com**

***Catch up with Max and his up-to-date topical discussions***



# TEACH-IN 2011

## A BROAD-BASED INTRODUCTION TO ELECTRONICS

## Part 5: Operational amplifiers

**By Mike and Richard Tooley**

**Our Teach-In series is designed to provide you with a broad-based introduction to electronics. We have attempted to provide coverage of three of the most important electronics units that are currently studied in many schools and colleges in the UK. These include Edexcel BTEC Level 2 awards, as well as electronics units of the new Diploma in Engineering (also at Level 2). The series will also provide the more experienced reader with an opportunity to 'brush up' on specific topics with which he or she may be less familiar.**

**Each part of our Teach-In series is organised under five main headings; Learn, Check, Build, Investigate and Amaze. Learn will teach you the theory, Check will help you to check your understanding, and Build will give you an opportunity to build and test simple electronic circuits. Investigate will provide you with a challenge which will allow you to further extend your learning, and finally, Amaze will show you the 'wow factor'!**

INTEGRATED circuits (ICs) comprise large numbers of transistors and other components built on a single small slice of silicon. This allows complex circuits, such as a complete radio receiver, to be built in a package that's smaller than the nail on your little finger. Any additional components, such as inductors and capacitors (difficult to manufacture in integrated circuit form) and other components that need to be externally accessible are then connected as external 'discrete' components.

In this instalment of *Teach-In 2011*, we will be investigating one of the most common types of integrated circuit, the operational amplifier (*op amp*). In ***Build***, you will be using Circuit Wizard to simulate a variety of operational amplifier circuits, while ***Investigate*** challenges you to explain the operation of a simple oscillator circuit. Finally, in ***Amaze***, we shall look back at the technology that we used before integrated circuits became available.

## Learn

### Integrated circuits

Used in a huge variety of different applications, operational amplifiers are probably the most common and versatile form of analogue integrated circuit. Fig. 5.1 shows the ubiquitous 741 operational amplifier, while Fig. 5.2 shows what's inside the 8-pin dual-in-line package.


*Fig.5.1. The famous 741 operational amplifier, which is supplied in an 8-pin dual-in-line package*

You can think of an operational amplifier as a universal 'gain block' to which a few external components are added in order to define the particular function of a circuit. For example, by adding just two external resistors, you can produce an amplifier having a precisely defined gain. From this you might begin to suspect that operational amplifiers are really easy to use. The good news is that they are!

## Op amp

The symbol for an operational amplifier is shown in Fig. 5.3. There are a few things you need to note about this.

The device has two inputs and one output and no common connection. Notice also that one of the inputs is marked '–' and the other is marked '+'. These polarity markings have nothing to do with the supply connections – they indicate the overall phase shift between each input and the output. The '+' sign indicates zero phase shift while the '–' sign indicates 180° phase shift.

Since 180° phase shift produces an inverted (ie, turned upside down) waveform, the '–' input is often referred to as the '*inverting input*'. Similarly, the '+' input is known as the '*non-inverting*' input. Furthermore, we often don't show the supply connections as it is often clearer to leave them out of the circuit altogether and just assume that they are connected to every chip!

Most (but not all) operational amplifiers require a symmetrical supply of typically between ±6V and ±15V. This allows the output voltage to swing both positive (above 0V) and negative (below 0V). Figure 5.4 shows how the supply connections would appear if we decided to include them. Note that we usually have two separate supplies; a positive supply and an equal, but opposite, negative supply. The common connection to these two supplies (i.e., the 0V rail) acts as the common rail in our circuit. The input and

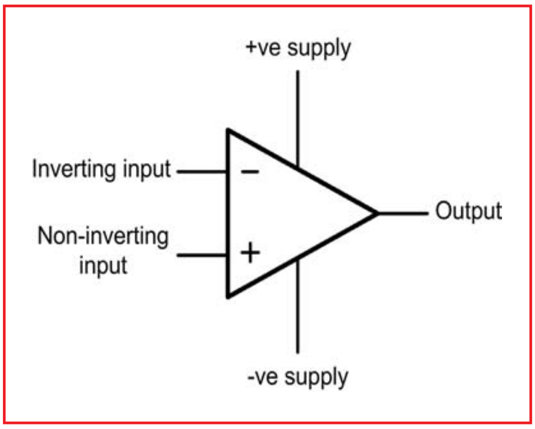



*Fig.5.3. Symbol for an operational amplifier*

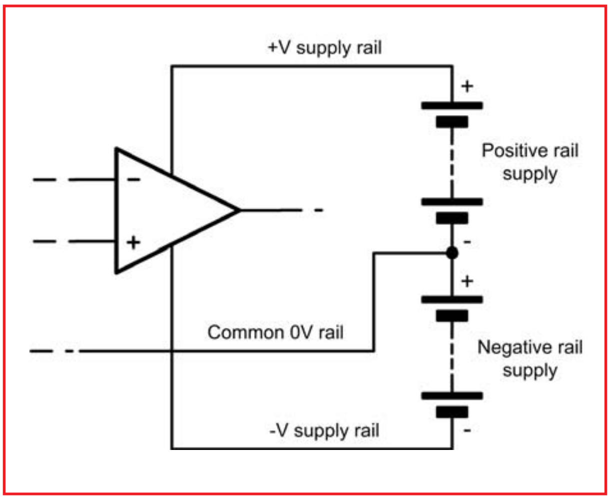
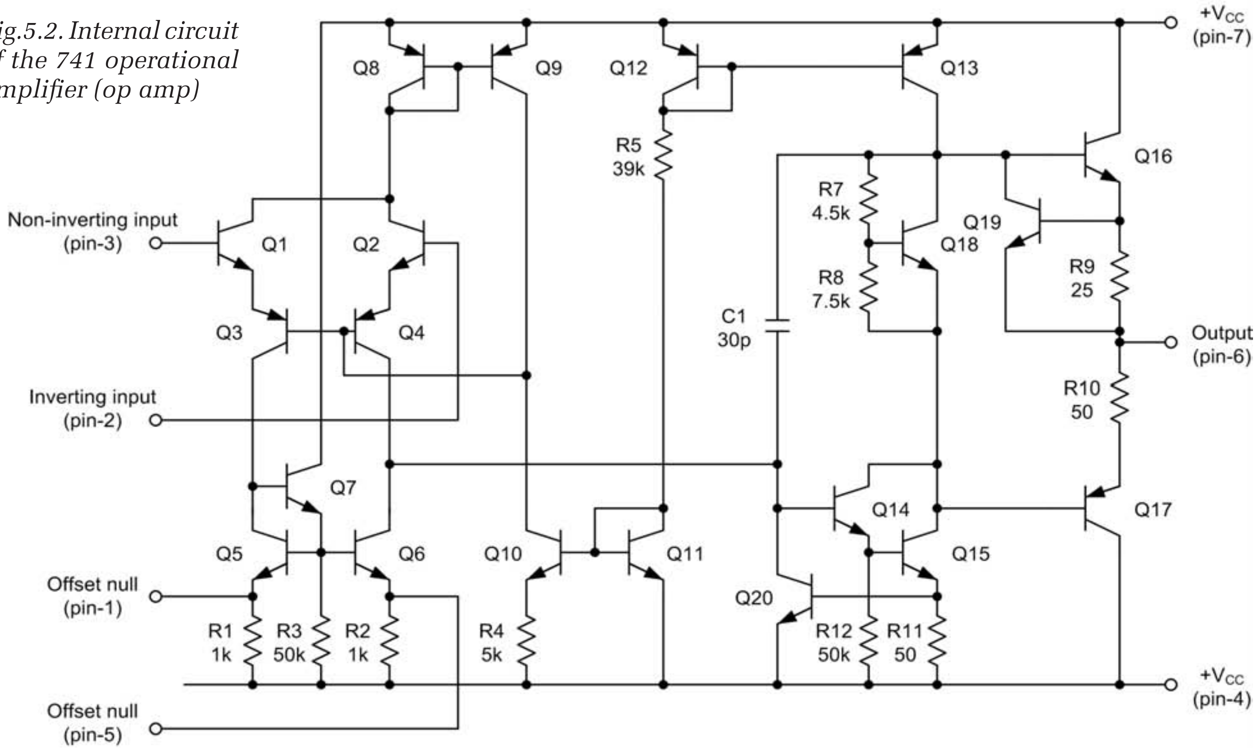



*Fig.5.4. Supply rails for an operational amplifier*

*Fig.5.2. Internal circuit of the 741 operational amplifier (op amp)*



output voltages are usually measured relative to this rail.

## Gain

Before we take a look at some of the characteristics of operational amplifiers, it is important to define some of the terms and parameters that we apply to amplifiers generally. One of the most important of these is the amount of amplification or '*gain*' that a device provides. To keep things as simple as possible we will use an 'equivalent circuit' to represent an amplifier, as shown in Fig.5.5. This is much easier to work with than the circuit that we met earlier in Fig.5.2.

In Fig.5.5 the amplifier is represented by a 'black box', with two input and two output terminals. Note that in practice, one of the input terminals is often directly linked to one of the output terminals and then referred to as 'common'. The input resistance ($R_{in}$ in Fig.5.5) is the resistance that we would 'see' looking into the two input terminals, while the output resistance ($R_{out}$ in Fig.5.5) is the resistance that we would 'see' looking back into the two output terminals. The voltage produced by the amplifier is shown as a 'constant voltage generator' (the circle with the sinewave inside).

Gain is simply the ratio of what we get out to what we put in. So, for example, voltage gain is defined as the ratio of output voltage to input voltage. As a formula, this is:

$$A_v = \frac{V_{out}}{V_{in}}$$

where $A_v$ represents voltage gain and $V_{out}$ and $V_{in}$ are the output and input voltages respectively.

Similarly, current gain is defined as the ratio of output current to input current. As a formula, this is:

$$A_i = \frac{I_{out}}{I_{in}}$$

where $A_i$ represents current gain and $I_{out}$ and $I_{in}$ are the output and input current respectively.

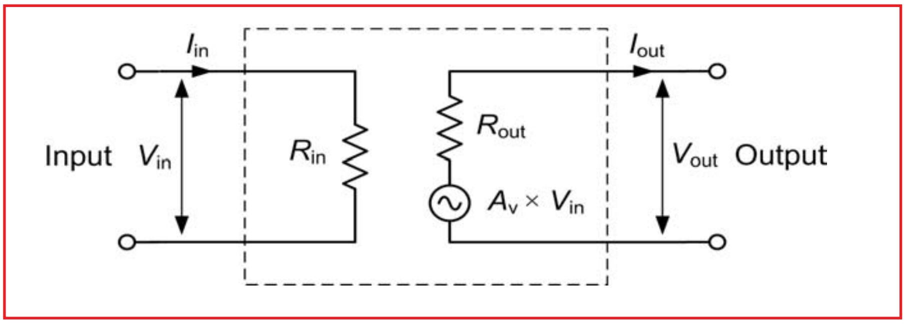



*Fig.5.5. Equivalent circuit of an amplifier*

Finally, the power gain of the amplifier is defined as the ratio of output power to input power. As a formula, this is:

$$A_p = \frac{P_{out}}{P_{in}}$$

where $A_p$ represents voltage gain and $P_{out}$ and $P_{in}$ are the output and input voltages respectively.

Now power is the product of voltage and current, thus:

$$P_{out} = I_{out} \quad V_{out} \text{ and } P_{in} = I_{in} \quad V_{in}$$

Combining these relationships gives:

$$A_p = \frac{I_{out} V_{out}}{I_{in} V_{in}} = A_i \quad A_v$$

This tells us that the *power gain* of an amplifier is the *product* of the *current gain* and *voltage gain*.

## Input resistance

The *input resistance* of an amplifier is defined as the ratio of input voltage to input current:

$$R_{in} = \frac{V_{in}}{I_{in}}$$

where $R_{in}$ is the input resistance (in ohms), $V_{in}$ is the input voltage (in volts) and $I_{in}$ is the input current (in amps).

## Output resistance

The *output resistance* of an amplifier is defined as the ratio of open-circuit output voltage to short-circuit output current. Thus:

$$R_{out} = \frac{V_{out(oc)}}{I_{out(sc)}}$$

where $R_{out}$ is the output resistance (in ohms), $V_{out(oc)}$ is the open-circuit output voltage (in volts) and $I_{out(sc)}$ is the short-circuit output current (in amps).

### Example 1

An amplifier produces an output voltage of 2V when supplied with an input of 4mV. Determine the value of voltage gain of the amplifier.

### Solution

Now:

$$A_v = \frac{V_{out}}{V_{in}}$$

Thus:

$$A_v = \frac{2}{4 \times 10^{-3}} = \frac{2 \times 10^3}{4} = 500$$

### Example 2

An amplifier has an input resistance of 2MΩ. What current will flow into the input of the amplifier when a voltage of 50mV is applied?

### Solution

Now:

$$R_{in} = \frac{V_{in}}{I_{in}}$$

Thus:

$$I_{in} = \frac{V_{in}}{R_{in}} = \frac{50 \times 10^{-3}}{2 \times 10^6}$$

$$= 25 \times 10^{-9} \text{ A} = 25 \text{ nA}$$

### Please note!

Equivalent circuits provide us with a way of understanding the behaviour of electronic devices and circuits operate.

## Operational amplifier characteristics

Having now defined the parameters that we use to describe amplifiers, it is worth considering the characteristics

that we would associate with an 'ideal' amplifier. These are:

(a) The voltage gain should be as large as possible, so that a large output voltage will be produced by a small input voltage

(b) The input resistance should be as large as possible, so that only a small input current will be taken from the signal source

(c) The output resistance should be as low as possible, so as not to limit the output current and power delivered by the amplifier

(d) Bandwidth should be as wide as possible so as not to limit the frequency response of the amplifier.

Fortunately, the characteristics of most modern operational amplifiers come very close to those of an 'ideal' operational amplifier, as shown in Table 5.1.

Table 5.1. Ideal and typical characteristics **of an operational amplifier**

| *Parameter* | *Ideal* | *Typical* |
|---|---|---|
| Voltage gain | Very high | 100,000 |
| Input resistance | Very high | 100MΩ |
| Output resistance | Very low | 20Ω |
| Bandwidth | Very wide | 2MHz |

## Gain and bandwidth

It is important to note that the product of gain and bandwidth is a constant for any particular operational amplifier. This means that an increase in gain can only be achieved at the expense of bandwidth, and *vice versa*. In practice, we control the gain (and bandwidth) of an operational amplifier by applying a fixed amount of negative feedback.

Figure 5.6 shows the relationship between voltage gain and bandwidth for a typical operational amplifier (note that the axes use logarithmic, rather than linear scales). The open-loop voltage gain (ie, that obtained with no external feedback applied) is 100,000 and the bandwidth obtained in this condition is a mere 10Hz. The effect of applying increasing amounts of negative feedback (and consequently reducing the gain to a more manageable amount) is that the bandwidth increases in direct proportion.

## Frequency response

The frequency response curves in Fig.5.6 show the effect on the bandwidth of making the closed-loop gains equal to 10,000, 1,000, 100, and 10. Table 5.2 summarises these results. You should also note that the (gain × bandwidth) product for this amplifier is $1 \times 10^6$Hz (ie, 1MHz).

We can determine the bandwidth of the amplifier when the closed loop voltage gain is set to a particular value by constructing a line and noting the intercept point on the response curve.

### Please note!

The product of gain and bandwidth for an operational amplifier is a constant. Thus an increase in gain can only be achieved at the expense of bandwidth, and *vice versa*.

### Please note!

When negative feedback is applied to an amplifier the overall gain is reduced and the bandwidth is increased. When positive feedback is applied to an amplifier the overall gain increases and the bandwidth is reduced. In most cases this will result in instability and oscillation.

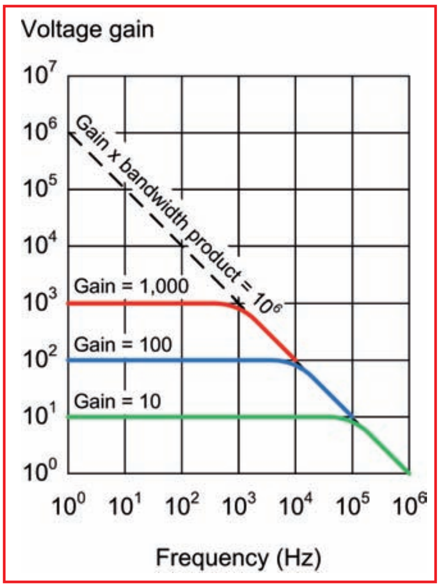



Fig.5.6. Frequency response curves for *an operational amplifier*

Table 5.2. Relationship between voltage gain and **bandwidth for an operational amplifier** with a gain-bandwidth product of 1MHz

| *Voltage gain ($A_V$)* | *Bandwidth* |
|---|---|
| 1 | DC to 1MHz |
| 10 | DC to 100kHz |
| 100 | DC to 10kHz |
| 1000 | DC to 1kHz |
| 10000 | DC to 100 Hz |
| 100000 | DC to 10 Hz |

## Amplifier configurations

The three basic configurations for operational voltage amplifiers are shown in Fig.5.7. As mentioned earlier, supply rails have been omitted from these diagrams for clarity but are assumed to be symmetrical about 0V.

The voltage gain for the inverting amplifier shown in Fig. 5.7(a) is given by the expression:

$$A_V = \frac{V_{out}}{V_{in}} = -\frac{R_F}{R_{IN}}$$

The minus sign in the voltage gain expression is included to indicate inversion (ie, a positive input voltage will produce a negative output voltage, and *vice versa*). To preserve symmetry and minimise offset voltage, a third resistor is often included in series with the non-inverting input. The value of this resistor should be equivalent to the parallel combination of $R_{IN}$ and $R_F$. Hence:

$$R = \frac{R_F \times R_{IN}}{R_F + R_{IN}}$$

The voltage gain for the non-inverting amplifier shown in Fig.5.7(b) is given by the expression:

$$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R_{IN}}$$

Finally, the voltage gain for the differential amplifier shown in Fig.5.7(c) is given by the expression:

$$A_V = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_2 - V_1} = \frac{R_F}{R_{IN}}$$

Where $V_1$ and $V_2$ are the voltages at the input resistance ($R_{IN}$) connected to inverting and non-inverting inputs respectively.

## Limit capacitor

All of the amplifier circuits described previously have used direct coupling and thus have frequency response characteristics that extend to DC. This, of course, is undesirable for many applications, particularly where a wanted AC signal may be superimposed on an unwanted DC voltage level.

In such cases a capacitor of appropriate value may be inserted in series with the input, as shown below. The value of this capacitor should be chosen so that its reactance is very much smaller than the input resistance at the lower applied input frequency.

We can also use a capacitor to restrict the upper frequency response of an amplifier. This time, the capacitor is connected as part of the feedback path. Indeed, by selecting appropriate values of capacitor, the frequency response of an inverting operational voltage amplifier may be very easily tailored to suit individual requirements (see Fig.5.8 and Fig.5.9).

The lower cut-off frequency is determined by the value of the input capacitance, C1, and input resistance, R1. The lower cut-off frequency is given by:

$$f_1 = \frac{1}{2\pi C1R1} = \frac{0.159}{C1R1}$$

Where C1 is in farads and R1 is in ohms.

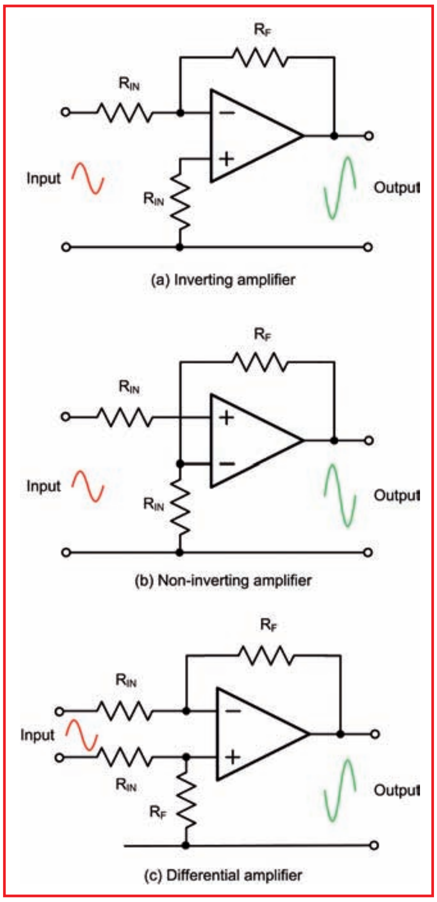



*Fig.5.7. The three basic configurations for operational voltage amplifiers*

Provided the upper frequency response it not limited by the gain × bandwidth product, the upper cut-off frequency will be determined by the feedback capacitance, C2, and feedback resistance, R2, such that:

$$f_1 = \frac{1}{2\pi C2R2} = \frac{0.159}{C2R2}$$

Where C2 is in Farads and R2 is in ohms.

## Example 3

An inverting operational amplifier is to be designed to the following specification:

Voltage gain = 20

Input resistance (at mid-band) = 10k ?

Lower cut-off frequency = 100Hz

Upper cut-off frequency = 10kHz

Devise a circuit to satisfy the above specification using an operational amplifier.

## Solution

To make things a little easier, we can break the problem down into manageable parts. We shall base our circuit on a single operational amplifier configured as an inverting amplifier with capacitors to define the upper and lower cut-off frequencies, as shown in the Fig.5.8.

The nominal input resistance is the same as the value for R1.

Thus:

$$R1 = 10k\Omega$$

To determine the value of R2 we can make use of the formula for mid-band voltage gain:

$$A_V = R2/R1$$

Thus:

$$R2 = A_V \times R1 = 20 \times 10k\Omega = 200k\Omega$$

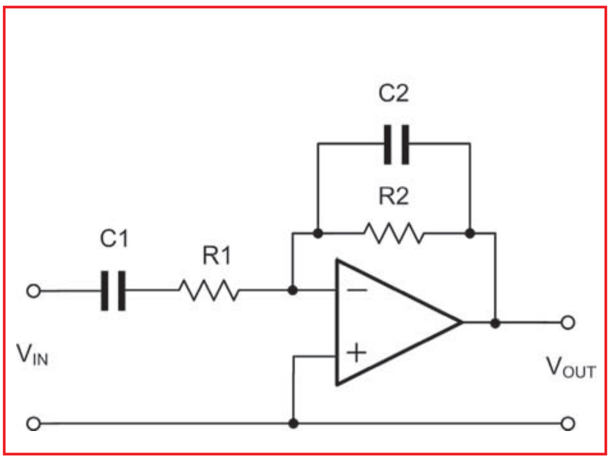



*Fig.5.8. An inverting amplifier with capacitors to limit* both the low and the high frequency response

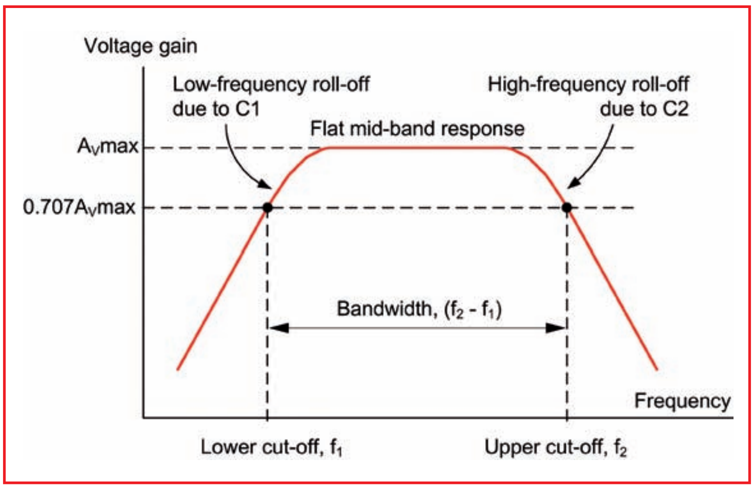



*Fig.5.9. Amplifier frequency response*

To determine the value of C1 we will use the formula for the low frequency cut-off:

$$f_1 = \frac{0.159}{C1R1}$$

From which:

$$C1 = \frac{0.159}{f_1 R1} = \frac{0.159}{100 \times 10 \times 10^3}$$

$$= \frac{0.159}{1 \times 10^6} = 0.159 \times 10^{-6}\ \text{F} = 159\text{nF}$$

Finally, to determine the value of C2 we will use the formula for high frequency cut-off:

$$f_2 = \frac{0.159}{C2R2}$$

From which:

$$C2 = \frac{0.159}{f_2 R2} = \frac{0.159}{10 \times 10^3 \times 200 \times 10^3}$$

$$= \frac{0.159}{2 \times 10^9} = 0.159 \times 0.5 \times 10^{-9}\ \text{F} = 80\text{pF}$$

The circuit of the amplifier is shown in Fig. 5.10.

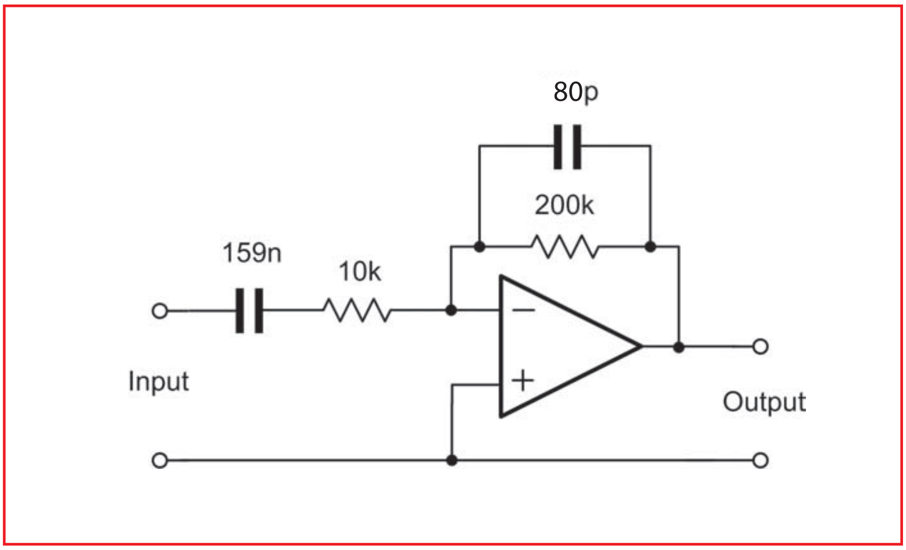


Fig.5.10. Complete amplifier circuit showing component values for Example 3

## Other applications

As well as their application as a general purpose amplifying device, operational amplifiers have a number of other uses. We shall conclude this month's Learn by taking a brief look at two of these, voltage followers and comparators.

A voltage follower using an operational amplifier is shown in Fig.5.11. This circuit is essentially a non-inverting amplifier in which 100% of the output is fed back to the input. The result is an amplifier that has a voltage gain of 1 (ie, 'unity'), a very high input resistance and a very high output resistance. This stage is often referred to as a buffer and is used for matching a high-impedance circuit to a low-impedance circuit.

Typical input and output waveforms for a voltage follower are shown in Fig.5.12. Notice how the input and output waveforms are both in-phase (they rise and fall together) and that they are identical in amplitude.

A comparator using an operational amplifier is shown in Fig.5.13. Since no negative feedback has been applied, this circuit uses the maximum gain of the operational amplifier.

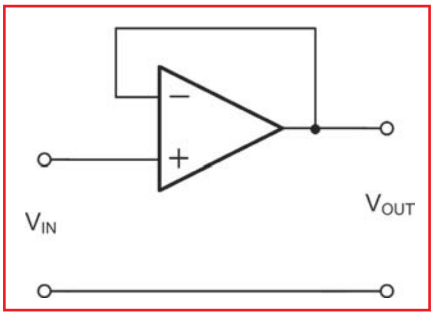


Fig.5.11. A voltage follower

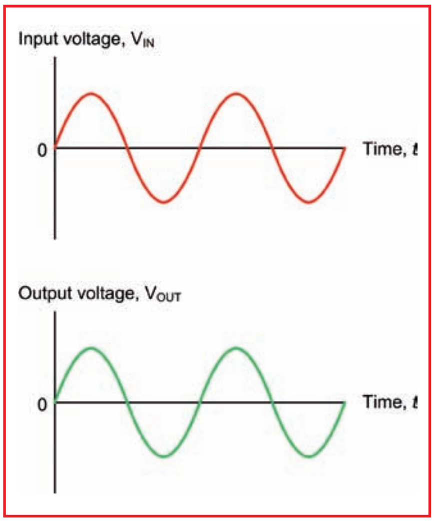


Fig.5.12. Typical input and output waveforms for a voltage follower

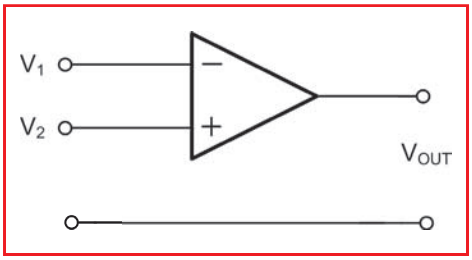


Fig.5.13. A comparator

The output voltage produced by the operational amplifier will thus rise to the maximum possible value (equal to the positive supply rail voltage) whenever the voltage present at the non-inverting input exceeds that present at the inverting input. Conversely, the output voltage produced by the operational amplifier will fall to the minimum possible value (equal to the negative supply rail voltage) whenever the voltage present at the inverting input exceeds that present at the non-inverting input.

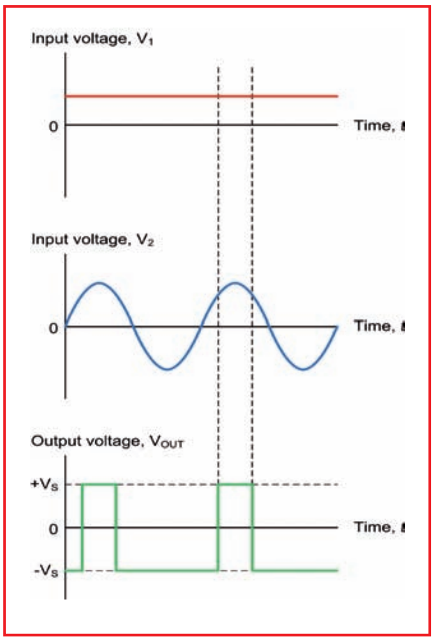


Fig.5.14. Typical input and output waveforms for a comparator

Typical input and output waveforms for a comparator are shown in Fig.5.14. Notice how the output is either +15V or –15V depending on the relative polarity of the two inputs.

## Check – How do you think you are doing?

5.1. Sketch the circuit symbol for an operational amplifier. Label each of the connections.

5.2. Sketch an equivalent circuit for an amplifier showing the input and output resistances. Label your drawing .

5.3. List four desirable characteristics of an 'ideal' amplifier.

5.4. An amplifier produces an output of 1.5V when an input of 7.5mV is present. Determine the value of the voltage gain.

5.5. An amplifier has a voltage gain of 50 and a current gain of 2,000. What power gain does the amplifier have?

5.6. Sketch the circuit of an inverting amplifier based on an operational amplifier. Label your circuit and identify the components that determine the voltage gain of the amplifier.

5.7. An inverting operational amplifier is to have a mid-band voltage gain of –15, an input resistance of 5k? , and a frequency response extending from 20Hz to 10kHz. Devise a circuit and specify all component values required.

For more information, links and other resources please check out our Teach-In website at:

www.tooley.co.uk/teach-in

## The Circuit Wizard way

NOW we've heard the theory, let's use Circuit Wizard to try out some practical operational amplifier circuits. Circuit Wizard is a really neat way to explore this kind of theory because students often find it hard to successfully build operational amplifiers circuits on prototyping boards.

This might be due to needing dual rail power supplies, or the fact that students find it hard to transpose the schematic diagram into a 'real life' circuit where incorrect layout can cause confusing results! Fortunately, we can do away with these problems when investigating these devices using Circuit Wizard. So let's look at a simple operational amplifier circuit connected in a non-inverting amplifier configuration.

### Please note!

When capturing a schematic based on operational amplifiers it is important to double check the orientation of the two signal input pins. By default, Circuit Wizard will draw an operational amplifier with the non-inverting input (labelled '+') at the top and the non-inverting input (labelled '–') at the bottom. This may or may not be the same as the circuit you are entering – so make sure that you double check!

Fortunately, it's really easy to change this; just right-click the op amp and click 'arrange' then 'mirror' (see Fig.5.15). It is important to note that by 'mirroring' the op amp, the supply connections remain unchanged, ie the positive supply at the top and negative at the bottom.

### Inverting amplifier

With the foregoing in mind, enter the circuit shown in Fig.5.16. In this circuit we have a 2V variable input voltage connected to our inverting input, with our non-inverting input connected to ground (0V). Recalling what we learned earlier,

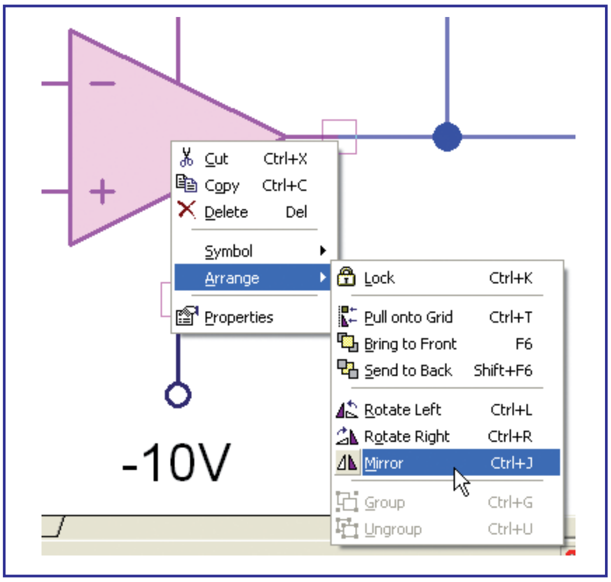



*Fig.5.15. Mirroring an operational amplifier to obtain the correct orientation of inverting and non-inverting inputs*

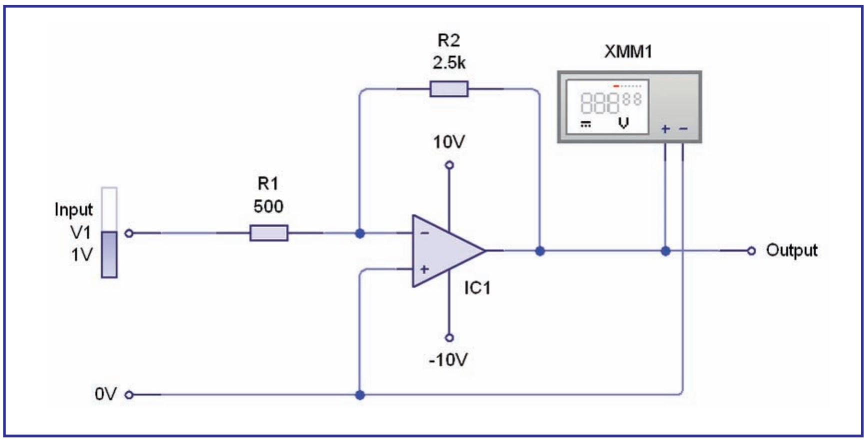



*Fig.5.16. A simple inverting amplifier circuit*

we know that the basic principle of the operational amplifier is to amplify the difference in voltage between the two inputs.

The amount of amplification provided by the circuit shown in Fig.5.16 is determined by the gain, which will depend on the arrangement and values of the resistors in the circuit. We learnt that we can calculate the gain of an inverting operational amplifier using the formula:

$$\text{Voltage gain} = -\frac{R_F}{R_{IN}}$$

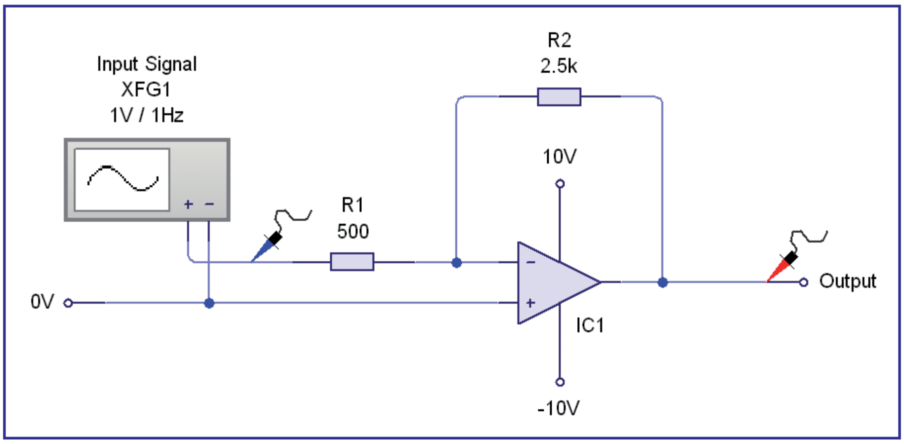



*Fig.5.17. Modified inverting operational amplifier circuit*

In our circuit, $R_F$ (R2) is 2.5k ? and $R_{IN}$ (R1) is 500 ?. Use the formula above to prove that the gain of this circuit is –5. In simple terms, this means that we should expect our output voltage to be –5 times larger than the input voltage. Note the minus sign; the output will be inverted, as its name suggests.

Now set the input voltage to 1V and run the simulation. We would expect the output voltage to be –5 × 1V = –5V. Now experiment with changing the input voltage and monitoring the output voltage. You should see that the gain holds true whatever the input voltage up until the output reaches the supply voltage. At this point, the output voltage will remain constant, even with increased input voltage. Whereas this might be fine for some circuits, when used in audio circuits this can cause clipping of the waveform, which can distort the sound.

Modify your circuit by replacing the variable input voltage with a function generator and adding some probes, as shown in Fig.5.17. The waveform display in Fig.5.18 shows how the signal has been amplified.

## Comparator

In our second circuit we'll investigate an operational amplifier configured as a comparator. This circuit 'compares' two input voltages and amplifies the resulting difference.

The inverting input is a simple potential divider that sets the voltage to half of the supply voltage, in this case 5V. The non-inverting input is connected to a potentiometer; effectively a variable potential divider. This allows us to control the voltage to this input.

In practical circuits this might be replaced with a potential divider involving a resistive input device, such as a light dependent resistor (LDR) or thermistor (we'll be looking at a circuit using an LDR next). Some circuits even use two variable inputs to be compared – for example a line following robot might compare the inputs from two LDRs to determine its orientation on a line.

Enter the comparator circuit shown in Fig.5.19 and experiment with the circuit by changing the potentiometer and observing the input/output voltages. Try switching to 'current flow' or 'voltage level' views to analyse the operation of the circuit. By changing the potentiometer you are changing the voltage at the non-inverting input. The inverting input is held at a constant voltage of about 5V.

When the non-inverting input voltage is higher than the inverting input, this difference is amplified by the operational amplifier. With no feedback resistors the gain is very large, and therefore the output swings to the maximum voltage possible; the supply

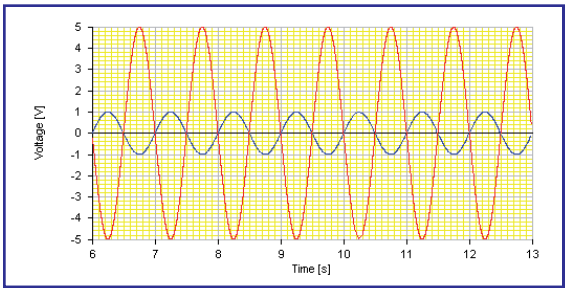



Fig.5.18. Waveform graph produced by the modified inverting operational amplifier. The input signal is shown in blue and the output in red

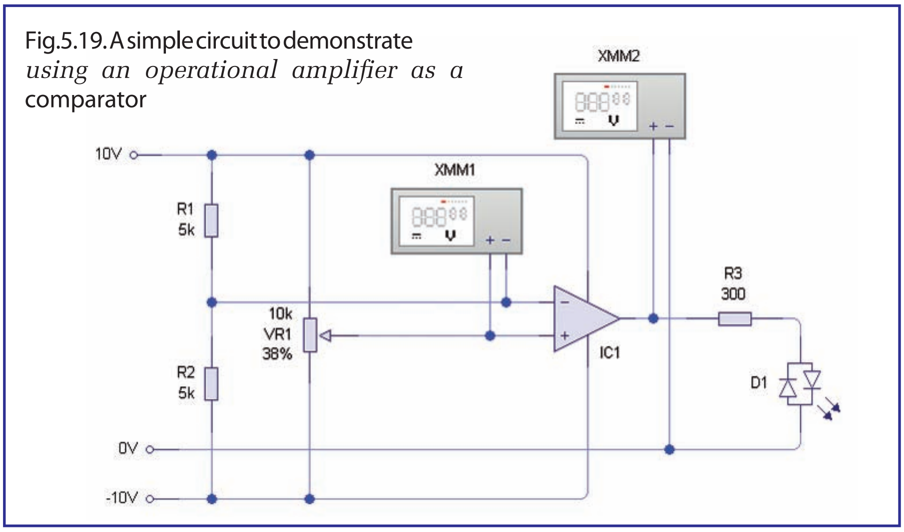



Fig.5.19. A simple circuit to demonstrate using an operational amplifier as a comparator

## The Circuit Wizard way

voltage. Current flows from the operational amplifier through the bi-colour LED (D1) to ground (0V), lighting it red to demonstrate a positive output. Conversely, when the non-inverting input is less than that of the inverting input, the amplifier amplifies the negative input by a large amount, resulting in an output at the negative supply and hence lighting the green LED.

Notice that despite what you may have thought, it is practically impossible to get an exact 0V output. This would, theoretically, be possible if we can ensure that both inputs were exactly the same. However, in practice, it is not possible to be this accurate, and the large gain and tiny variation results in a full swing either to fully positive or negative.

### Auto Light Switch

In our final circuit, we'll see a practical application of the comparator circuit we played with above. In this circuit, we'll use an LDR to monitor the light level and automatically turn on a lamp (LA1), for example for an automatic light circuit. Enter and simulate the circuit shown in Fig.5.20 and observe its operation. By adjusting the potentiometer we can set the point at which the lamp turns on. In practice, this would be how dark it is when you would like the light to turn on.

You may be wondering why using an op amp for this purpose is better than using a simple transistor switch circuit. By using an operational amplifier, as soon as we hit the preset voltage (the non-inverting input voltage) the operational amplifier will greatly amplify the input and immediately give us the full supply voltage. However, using only a transistor switch you tend not to get a precise on/off because often there is a period where the transistor is not completely saturated.

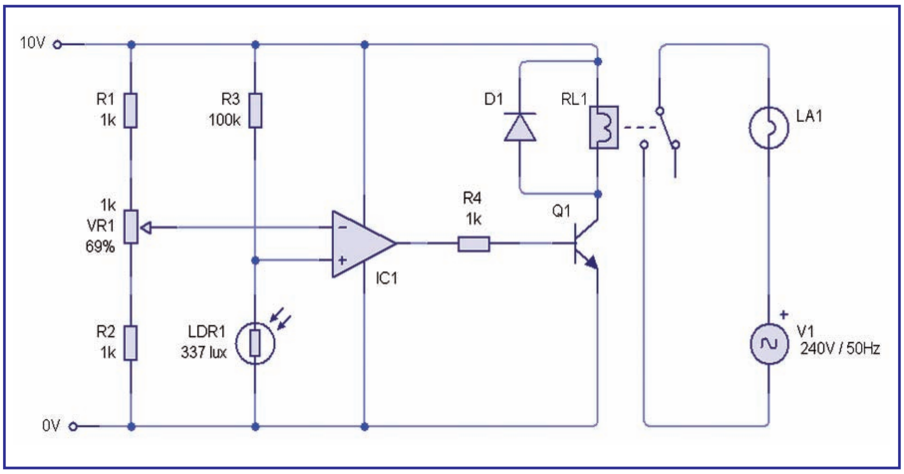



*Fig.5.20. An automatic light switch using a comparator circuit*

## Investigate

An oscillator circuit is simply a circuit that provides an output signal without needing any input (apart from a power supply – of course!). Fig.5.21 shows the circuit of a simple oscillator circuit based on a single operational amplifier. Enter the circuit in Circuit Wizard, investigate the output that it produces and then see if you can explain how the circuit works.

*Hint:* You might need to recall earlier work that you did on *C-R* charging and discharging circuits and combine this with what you now know about operational amplifier comparators.

You will find that Circuit Wizard will do a great job of simulating the oscillator circuit. However, because there's a lot going on in a short amount of time, it can't do it in real time. If you try at full speed you'll most likely get very confusing results. To 'slow things down' you can reduce the speed of simulation by clicking on 'Time:' on the grey bar at the bottom of the Circuit Wizard window; 10ms should work nicely with most computers.

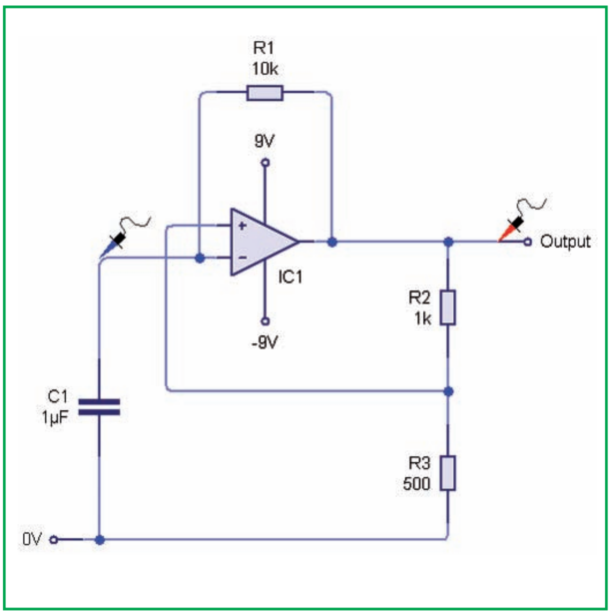



*Fig.5.21. An operational amplifier being used in an oscillator circuit*

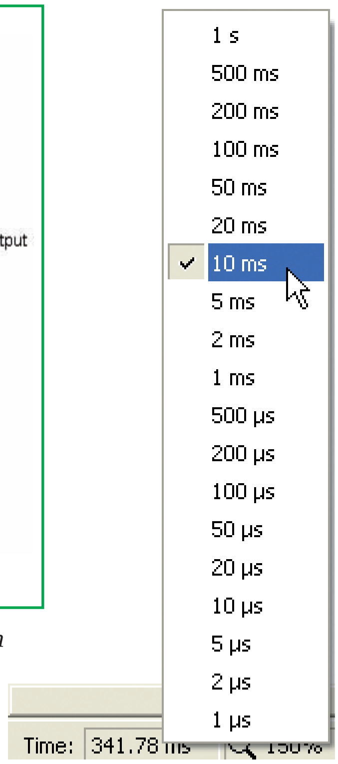



*Fig.5.22(right). Changing simulation speed in Circuit Wizard*

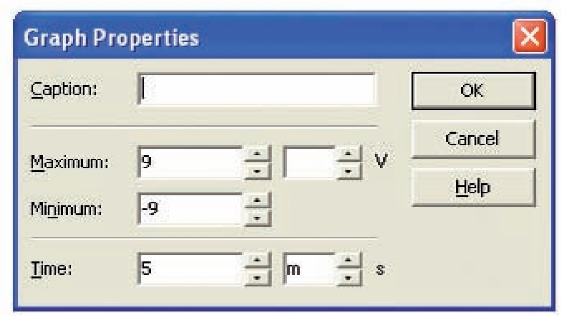



*Fig.5.23(above). Suggested graph parameters*

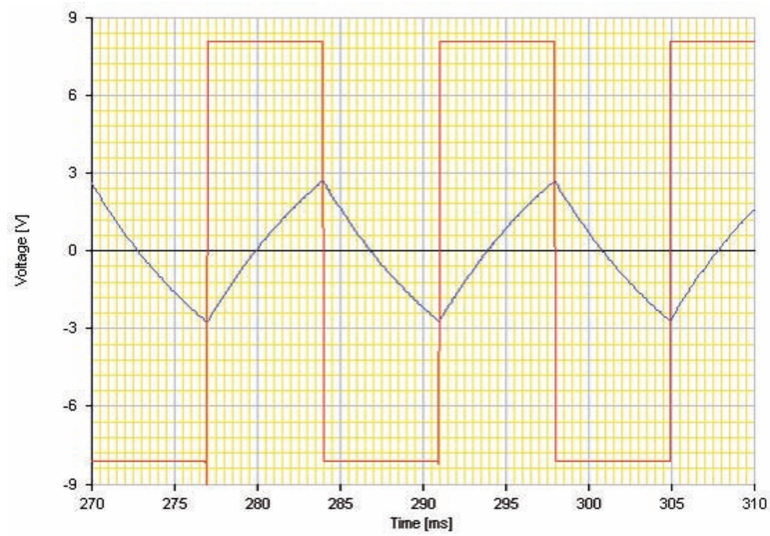



*Fig.5.24(right). Typical waveforms produced by the oscillator circuit*

If your computer is a bit on the slow side, opt for less until you get a nice looking trace (see Fig.5.22). You will also need to adjust the scale on your graph; Fig.5.23 shows some suggested values that will give you a graph like that shown in Fig.5.24. The rest is for you to investigate… so how does it do it? The blue trace/probe in Fig. 5.24 should give you some clues!

## Answers to Questions

5.1. See Fig.5.3

5.2. See Fig.5.5

5.3. See page 51

5.4. 200

5.5. 100,000

5.6. See Fig.5.7(a)

5.7. See Fig.5.8 with R1 = 5kΩ, R2 = 75kΩ, C1 = 1.59µF, C2 = 212pF

## Amaze

Before we could use transistors in electronic circuits, we had to use valves. These looked a bit like light bulbs. They needed lots of space, lots of power and often produced a lot of heat (they had to be heated up internally before they could work). This made designing simple circuits quite complicated – not only did we need a low-voltage high-current heater supply, but we also needed a high voltage supply of around 200V or more.

When transistors came along, they revolutionised electronics, making it possible to have small, complex circuits that operated from low voltage. Today, we can make transistors so tiny that we can fit literally millions of them on an area the size of your small finger.

The current generation of microprocessors are manufactured using a process that's capable of producing individual transistors 1,000 times smaller than the diameter of a human hair. That means that the individual semiconductor layers might only have a few tens or hundreds of atoms. In fact, the latest technology is capable of producing transistors that are less than 25nm across – that's a mere 0.000025mm!

*Fig.5.25. Valves from the 1940s and 1950s compared with transistors from the 1960s and 1970s*


## Circuit Wizard

A *Standard* or *Professional* version of Circuit Wizard can be purchased from the editorial office of *EPE* – see *CD-ROMs for Electronics* page and the UK shop on our website (**www.epemag.com**).

Further information can be found on the New Wave Concepts website; **www.new-wave-concepts.com**. The developer also offers an evaluation copy of the software that will operate for 30 days, although it does have some limitations applied, such as only being able to simulate the included sample circuits and no ability to save your creations.

### *Next month!*

In next month's Teach-In we will be investigating logic circuits.

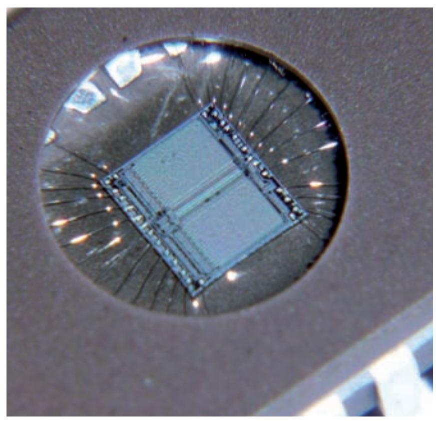


*Fig.5.26. This 1970s semiconductor memory device contains the equivalent of more than 65,000 individual transistors. The latest chips have more than 100 million devices in the same space!*

# CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

## Properties of comparators

Last month, we considered the problem of what to do with unused op amps after a post from ***Dave Larner*** on the *EPE Chat Zone.*

*If there is an unused op amp in a design, say using three of the four op amps on a chip, is it best to leave them floating or tie them to the ground or positive rails?*

Another issue which often arises with unused op amps in multi-amplifier packages is whether or not they should be used as comparators. Certainly, op amps *can* act as comparators, and doing so will keep the chip-count down, but are there pitfalls which need to be considered?

A related, but less common issue is whether a comparator could be used as an op amp. This was mentioned recently in a *Chat Zone* longer discussion started by ***terrym*** on the design of an infra-red, reflective object detector. Here ***alec_t*** posted:

*Not sure if the PIC's comparator would be happy working in a linear mode as an op amp. Does anyone know if it's really just an op-amp? Or does it have a Schmitt-trigger type snap action?*

This month we will look at some of the properties of comparators, discuss how they differ from op amps, and see what that implies about using spare op amps as comparators. We will also look briefly at the use of PIC comparators as op amps.

### In comparison

A comparator is a circuit which compares one analogue signal with another and outputs a binary signal based on the result of the comparison. In effect, it is a one-bit analogue-to-digital converter. An op amp used without negative feedback (open loop) has very high gain, thus for all but a small range of input voltage differences the output will be at the lowest or highest voltage available, typically close to the supply rails. These two saturated output voltages may represent Boolean 0 and 1.

An op amp used in this way behaves as a comparator. However its performance may differ from that of a circuit specifically designed to act as a comparator. To compare the two we need to define comparator characteristics and see how these relate to op amps.

The circuit symbol for a comparator is shown in Fig.1. A comparator's output voltage may be written mathematically as:

$$V_{out} = \begin{cases} V_{OH} & \text{if} \quad v_p > v_n \quad \Rightarrow \text{logic 1} \\ V_{OL} & \text{if} \quad v_p < v_n \quad \Rightarrow \text{logic 0} \end{cases}$$

Where $v_p$ and $v_n$ are the input voltages, as shown in Fig.1 and $V_{OH}$ is the logic 1, or high, output voltage, and $V_{OH}$ is the logic 0, or low, output voltage.

The above equation implies infinite gain and zero offset, $V_{OS}$. This means that an infinitely small voltage change around the reference voltage, $V_{ref}$, will cause the output to switch (infinite gain), and that this switching will occur exactly at the applied reference voltage (zero offset).

### Transfer characteristics

Fig.2 shows the effect of finite **gain** and **offset** on a comparator's transfer characteristic (relationship between input voltage difference and output voltage). The effect of the offset and finite gain is to reduce the resolution of the comparator, so that the difference between the inputs must be larger than a certain minimum to give reliable detection. Fig.2 represents the situation for static inputs, where the **resolution** is approximately $V_{OS} + V_{IH} = V_{OS} + V_{OH}/$*gain*, but typically the resolution will get worse for changing input signals.

In many applications, comparators are used to compare an input signal with a reference voltage generated within the circuit. In such cases, we can configure either inverting or non-inverting operation

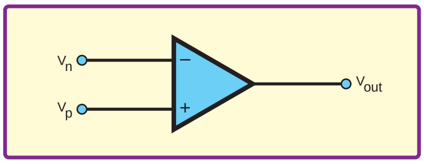



*Fig.1. Comparator symbol*

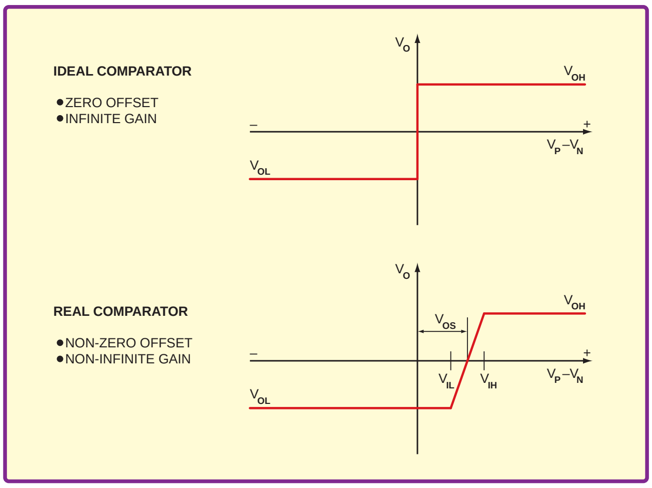



*Fig.2. Comparator transfer characteristics*

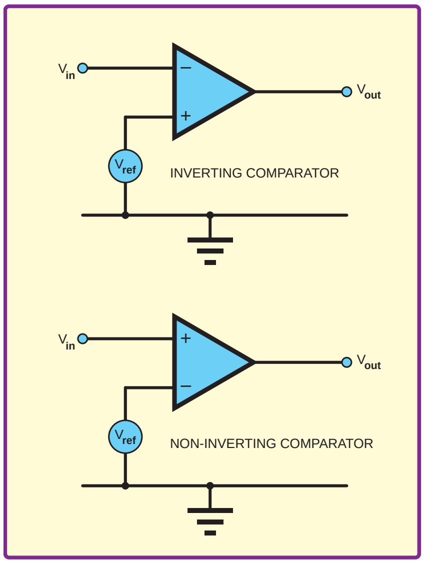



*Fig.3. Inverting and non-inverting comparator configurations*

depending on which of the comparator's inputs is connected to the reference and the input (see Fig.3). A non-inverting comparator has a high output (logic 1) when the input is greater than the reference. For an inverting comparator, a high output when the input is below the reference.

Op amps are designed to be used with negative feedback (eg, provided by the resistors used to set the circuit gain). All amplifiers have some delay from input to output, which results in increasing phase shift as signal frequency increases. At some point the phase shift reaches 180°, equivalent to inverting the signal, at which point the negative feedback network is actually delivering positive feedback.

If the gain of the amplifier and feedback network together is greater than one at this frequency oscillation will occur. The gain of most op amps is deliberately rolled off as frequency increases to prevent this instability – this is called compensation. Comparators are used open-loop or with positive feedback, so compensation is not required, leading to

significant differences between the two types of device.

Op amps are high-gain, linear, differential amplifiers; so in normal operation the voltage difference between an op amp's inputs is very small (typically microvolts to millivolts). Comparators often have much larger input differences. Not all op amps can tolerate large input voltage differences, and they perform very poorly, or may even by damaged under such conditions. Op amp input impedance may drop significantly for large input differences due to conduction of protection diodes – this could upset circuitry driving an op amp used as a comparator.

Similarly, comparators are commonly used to compare voltages which are not close to half the supply range. For an op amp this is a large common-mode input voltage. Again, not all op amps perform well under such conditions.

## Propagation delay

Gain and offset are characteristics shared by op amps and comparators. However, the switching behaviour of comparators means that they have characteristics related to switching which are not relevant to the standard analogue amplifier usage of op amps. The switching characteristics are illustrated in Fig.4, which shows comparator input and output waveforms for a non-inverting configuration with a fixed reference voltage.

When the comparator input voltage crosses the reference voltage, the comparator output will switch. This will not happen instantaneously – the time taken for the comparator output to reach 50% of the resulting voltage change is the **propagation delay**. The time taken for the comparator output voltage to rise from 10% to 90% of its range is the **rise time**. The amount of voltage applied to the comparator's input beyond the switching threshold (reference voltage) is known as **overdrive**.

Propagation delay and rise time are usually sensitive to overdrive, with increasing overdrive resulting in faster switching times. Comparator speed is also usually dependent on supply voltage.

The maximum rate of change of output voltage an op amp or comparator can deliver is the **slew rate**. Slew rate is important for op amps because it indicates how well the output voltage tracks fast-changing analogue waveforms; failure to track well causes distortion. Slew rate also directly determines the maximum frequency at which an op amp can produce a pure sinewave at full output swing (the full power

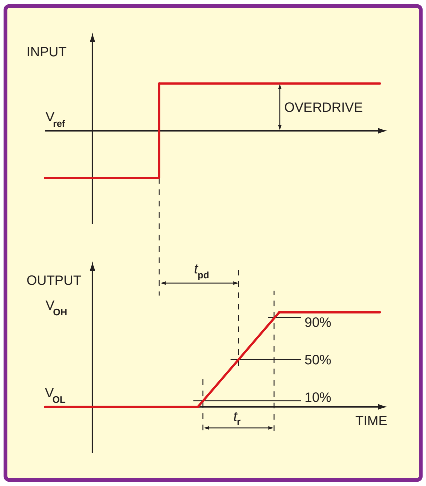



*Fig.4. Comparator propagation delay*

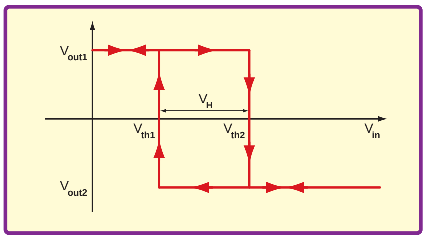



*Fig.5. Response of regenerative comparator*

bandwidth). However, sinewave output is of no relevance to comparators.

For any circuit used as a comparator, either the slew rate or the bandwidth may be the dominant factor in determining the propagation delay. Because comparators are just required to switch their outputs quickly, the slew rate itself is not usually very important as a specification, it is the propagation delay and rise time which are quoted. The compensation applied to op amps tends to reduce their slew rate, making them relatively slow when used as comparators.

A comparator's output will typically switch between the positive and negative supply voltages (or ground and supply in single-supply circuits). However, the output may switch, or it may be possible to arrange for it to switch, to a different voltage from the main comparator supply to facilitate interfacing to logic circuits. Often comparator output circuits are designed to be easy to interface with specific types of logic. Comparators are, therefore, available with a variety of output configurations, including push-pull, open drain or collector and LVDS (low voltage differential signalling). Open drain and open collector require an external resistor connected from the output to the positive (digital) supply.

Op amps are designed for usage where the output voltage does not hit the supply rails – this would normally imply clipping of the waveform and hence distortion. When op amp outputs are driven hard into saturation, they tend to be slow to recover. Like compensation, this makes op amps poor comparators where fast switching is required. The internal circuitry of comparators is designed to prevent the output stages going far into saturation, allowing them to recover very quickly. A further subtlety to this is that op amp saturation recovery time is likely to vary between individual devices, making the propagation delay somewhat unpredictable.

As we discussed last month, in the context of unused devices, op amps in multi-device packages (which is where we typically may want to use an op amp as a comparator) may be adversely influenced by other devices in the package being driven hard into saturation.

## Hysteresis

A comparator used with a single threshold (reference) value may switch states many times as a noisy, slowly changing input crosses the threshold. This is often undesirable, for example if the number of threshold-crossings is to be counted. The problem may be overcome by using two thresholds, eg $V_{TH}$ and $V_{TL}$. The difference between $V_{TH}$ and $V_{TL}$ is called the hysteresis.

A comparator with **hysteresis** can be made using a single simple comparator by setting the threshold depending on the current comparator output state. The comparator has two output states, so there are two thresholds as required. This arrangement uses positive feedback. Comparators with hysteresis are also known as **regenerative comparators** and **Schmitt triggers**.

The input-output response of a comparator with hysteresis is shown in Fig.5. When the input increases past $V_{TH}$ the comparator switches, but it does not switch back if the input decreases past $V_{TH}$. The input must decrease past $V_{TL}$ before the comparator switches again.

If the input noise level is known, the hysteresis can be set slightly larger than this. The comparator will then not switch as a result of the noise. Fig.6 and Fig.7 show the result of applying the same noisy signal to a simple comparator and one with hysteresis.

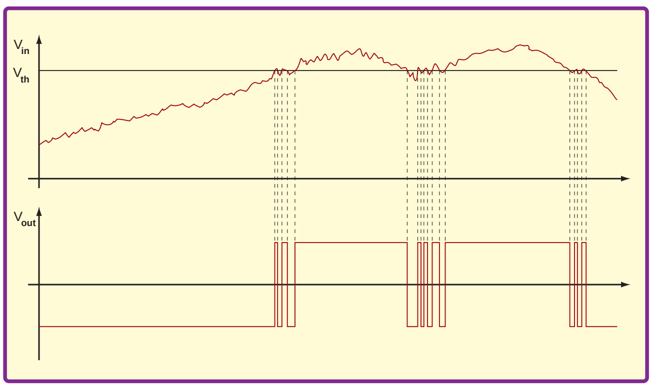



*Fig.6. Response of comparator without hysteresis*

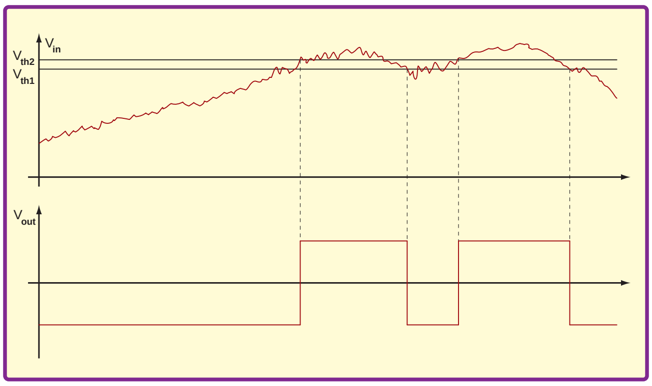



*Fig.7. Response of comparator with hysteresis*

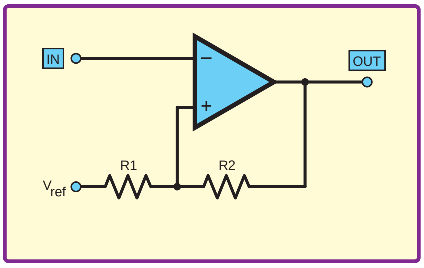



*Fig.8. Using positive feedback to apply hysteresis to a comparator*

A comparator with hysteresis can be made using a simple comparator with positive feedback. As the thresholds depend on the comparator's output voltages, these should be accurately controlled.

Refer to Fig.8. The switching point $V_{comp}$ depends on $V_{ref}$ and $V_{out}$. $V_{ref}$ will usually be fixed, but $V_{out}$ depends on the current state of the comparator. $V_{out}$ can take one of two values, which we will assume to be $\pm V_O$. Initially, let us assume that $V_{in} < V_{comp}$ so $V_{out} = +V_O$. If $V_{in}$ is slowly increased this condition remains until $V_{in} = V_{comp} = V_A$ where:

$$V_A = \frac{R_2}{R_1 + R_2} V_{ref} + \frac{R_1}{R_1 + R_2} V_O$$

On switching at $V_{comp} = V_A$ the output changes to $V_{out} = -V_O$, changing the switching point to a new value, $V_{comp} = V_B$

$$V_B = \frac{R_{21}}{R_1 + R_2} V_{ref} - \frac{R_1}{R_1 + R_2} V_O$$

$V_{out}$ will now stay at $-V_O$ until the input falls below $V_{comp}$ again. The difference in the switching points, ie, the hysteresis, $V_H$, is

$$V_H = V_A - V_B = \frac{2R_1}{R_1 + R_2} V_O$$

## Summing up

In summary, op amps can be used as comparators, but not without difficulties, and only in slow-speed applications. If comparisons faster than around 1µs are required then it is probably necessary to use a dedicated comparator. Op amps may not perform well with large differential or common mode inputs, but such conditions are common in comparator applications – so the op amp's datasheet should be consulted on relevant capabilities. Interfacing an op amp output to logic may also be less straightforward than with a comparator specifically designed to drive logic inputs.

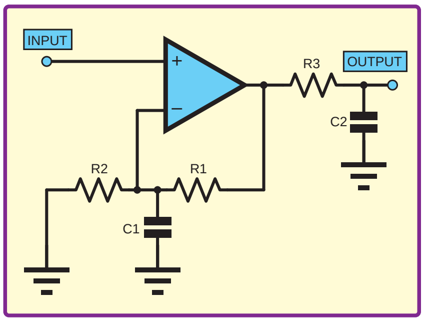



*Fig.9 Microchip circuit for using a PIC comparator as an op amp*

There are ICs which contain both comparators and op amps in a package, such as the TLV2704 and LTC1541. These might we worth considering rather than trying to use a spare device on a multi-op amp chip.

Use of comparators as op amps is often not possible and generally not easy. Comparators do not have the compensation circuitry which ensures that op amps are stable in negative feedback circuits, so this must be added to use a comparator as an op amp. If the comparator has specialised output circuitry for logic interfacing it is less likely to be usable as an amplifier. Also, if a comparator has some built-in hysteresis it is unlikely to be usable.

Finally, this brings us to alex_t's comment about comparators on PICs. Microchip indeed do provide details of how to use these comparators as op amps in their *Compiled Tips 'N Tricks Guide* (document code DS01146) available from **http://ww1.microchip.com/downloads/en/DeviceDoc/01146B.pdf**.

Microchip may have specifically designed their PIC comparators to be usable as a low speed op amp to increase the flexibility of this on-chip resource. However we have not read any documentation specifically stating this.

Fig.9 shows the non-inverting amplifier circuit recommended by Microchip – refer to the *Tips 'N Tricks* document for full details and calculation of component values. Note that capacitors are required to ensure stability. We assume that the comparator does not have built-in hysteresis, as this would inhibit its use as an op amp. Microchip describe how to add hysteresis using external resistors elsewhere in the same document.

# PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

## PIC-PROP 'chit-chat'

WE have reached the mid-point in our series of articles based around the Propeller processor. This month, we will complete the software that will reside on the processor, and move onto the design of the main PIC circuit. Remember that our aim is to develop a low cost, low power Internet computer; the Propeller design is just a part of the whole design.

If all goes well, this will be the last month we need to look at the Propeller processor in detail, although we may come back and tweak it a little.

### Developing the interface protocol

Let's now flesh out the way the two processors – the main control PIC microcontroller and the Propeller 'Media Processor' – talk to each other. In engineering terms, this is referred to as the 'protocol' by which they will communicate. The physical 'layer' of our design is implemented by a UART connection running at 11520 baud; the protocol is implemented by specifying how certain UART characters will be interpreted by the Media Processor to perform special actions.

What actions are performed is completely up to us, and will be determined by what special functions we would like the Media Processor to do. Obviously, displaying characters is important, but we also want to be able to change colours and move the print position around the display, among other things.

To start off, let's review the capabilities of the video output library provided by Parallax. It supports the following features:

- 128 × 64 characters, on a display resolution of 1024 x 768 pixels
- Characters are 8 pixels wide by 12 pixels high
- A font for 128 different characters is provided, including special 'graphics' characters for drawing boxes and lines
- Each display row can have its own foreground/background colour combination
- Individual characters may be inverted (by setting the most significant bit of the character code).

Besides the lack of full bit-mapped graphics capability, the main limitation is the lack of control over colour; we can only alter the colour of whole lines of text. This is just something that we have to bear in mind when we design the user-interface part of the main PIC application. Full colour control and bit-mapped graphics would be nice, but will have to wait for a later upgrade when the new Propeller-2 processor comes out in 2012 (the Propeller-2 is rumored to support high definition video output – that should be some upgrade!)

As the video library only supports 128 characters, we will use character values between 128 and 255 as special control characters, each one indicating a particular command. 128 commands is far more than we need, but it's nice to have the expansion capability. Each command can have one or more following characters as 'parameters', for example when setting the print position to an x,y location on the screen.

We will start off with a limited set of commands that we can build on later as we need them. This (initial) list of commands is shown in Table 1.

Also shown are the 'messages' sent back from the Propeller processor to the PIC. These are keyboard characters (individual characters in the range of 0 to 127) and mouse button actions, which are formatted as a command character 254 followed by the message identity and zero or more characters. To reduce the information sent to the PIC the current mouse position is only reported when a mouse button is pressed.

*Table.1 Message protocol*

| Character Code(s) | Function | Description |
|---|---|---|
| **From the PIC to the Propeller** | | |
| 128 | MOVE UP | Move print position up 1 character |
| 129 | MOVE DOWN | Move print position down 1 character |
| 130 | MOVE LEFT | Move print position left 1 character |
| 131 | MOVE RIGHT | Move print position right 1 character |
| 132 X Y | GOTO | Move print position to X,Y |
| 133 | HOME LEFT | Move print position to the far left. |
| 134 | CLEARSCREEN | Set the screen to the background colour and move print poition to 0,0 |
| 135 F B | SET LINE COLOUR | Sets the foreground and background colour of current line |
| 136 | INVERT CURRENT | Inverts the colour of the current character, and moves the cursor to the right |
| 137 | ECHO CHARS ON | Characters typed on the keyboard are displayed on screen |
| 138 | ECHO CHARS OFF | Characters typed on the keyboard are not displayed on screen |
| 139 X Y | MOVE CURSOR1 | Move the cursor to position X, Y |
| 140 | CURSOR1 ON | Display the flashing cursor at current position |
| 141 | CURSOR1 OFF | Turn the cursor off |
| 142 | MOUSE ON | Show the 'Mouse' cursor |
| 143 | MOUSE OFF | Hide the 'Mouse' cursor |
| **From the Propeller to the PIC** | | |
| 254 B X Y | MOUSE BUTTON | A mouse button has been pressed. B = Button : 0 LEFT, 1 RIGHT X, Y are position on screen. |
| Note: all values are transmitted as binary characters, not in ASCII. | | |

Obviously there is plenty of scope for this protocol to grow as we find new features that would be useful, but this is a good starting point.

The final important design consideration is how the display screen will be laid out, ie what the coordinate system is. Although the Propeller's display driver software has its own layout, there is nothing to stop us specifying our own, and then converting to the Propeller format. As it is, the Propeller implements a quite natural system – the top left corner of the screen is the origin (location 0,0) and the X coordinate increases as you move to the right, and the Y coordinate increases as you move down the screen. The X and Y coordinates refer to character positions, not pixel locations (as we cannot address individual pixels yet.)

The full source code for the Propeller implementation can be found on the *EPE* website. This should be compiled and programmed into the Propeller processor.

### Control processor

Now let's take a look at the main PIC control circuit. The choice of processor is wide, and whatever chip we use really only needs to be fast (by PIC standards) and have plenty of flash memory to store all our utility programs. To enable us to program in 'C' we are looking at PIC18F, PIC24F, DsPIC or PIC32 processor families.

We have chosen the PIC24HJ128GP202. The reasons are pretty simple: it's available in a nice 28-pin DIP package, it has a lot of flash memory space and it's a part we've used here before in *PIC n' Mix*. As it operates at 3.3V, it's I/O pins will be compatible with the Propeller processor, Micro SD-Media card and the Ethernet interface chip, which we will discuss later.

One nice feature of the PIC24 processor is that the internal peripherals, such as the UART interface, are not hard wired to particular pins. Sixteen of the twenty one I/O pins can be mapped to any of the 22 peripheral I/O functions. While this adds a small layer of complexity – at startup you have to select which pins go where – it can significantly reduce circuit board layout size. When you are trying to squeeze a design onto a small single or double-sided PCB, that can be a blessing.

Our part has 128KB of flash memory available for application software, which will be very useful as we build multiple applications into our little device.

The final factor affecting our choice of part is the availability of Microchip's free TCP/IP stack framework software, which as we will find out later, can be used almost 'out of the box' in our design.

## Control circuit

Our initial circuit is shown in Fig.1. This circuit will grow over the coming months, and for now only two signals connect it to the Propeller circuit – port pins RB14 and RB15, which will connect the two UARTS together. Note that as both these circuits are running at 3.3V, and will be very close to each other (possibly on the same circuit board), there are no RS232 converter chips. This circuit can draw its power from the same regulator as used on the propeller, since there is *plenty* of spare current capacity on the LD1086 IC.

A simple header lead could be used to connect the two circuits via the Propeller's programming header, and 3.3V and ground are available there. Don't be tempted to solder the two circuits together, because the Propeller's programming interface may well be used again later, as we upgrade its capabilities.

This circuit provides the minimum level of functionality to enable us to start working with the free PIC24 C compiler (called MPLAB C30) and test the Propeller's display capabilities. We will go through the installation and initial use of C30 next month, but for those of you who are familiar with it and would like to see a demonstration of what our system is capable of, a simple example PIC24 application is available on the magazine website for download alongside the main firmware for the Propeller.

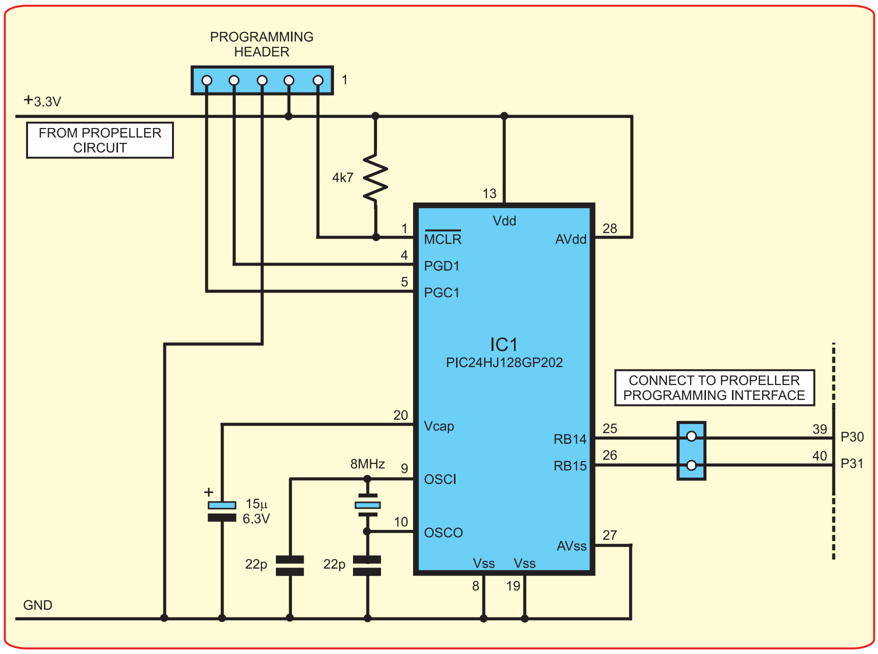



*Fig.1 PIC controller circuit diagram*

## Simulation

Developing any form of user interface is often tricky, and making the most of a text-based user interface can be even harder. Sometimes using a PC to simulate a display, or even using a PC to drive the media processor can simplify the task.

As the Propeller communicates with the PIC24 through a standard UART interface, you might want to experiment with driving the Propeller with a program on the PC – just make sure you use a MAX232 RS232 logic converter chip on the signals coming from the PC, otherwise the Propeller will be damaged.

# Practically Speaking

**Robert Penfold looks at the Techniques of Actually Doing it!**

WE seem to live in a world where practically every name or term seems to end up as either an acronym or an abbreviation. *Everyday Practical Electronics* is perhaps better known as *EPE* by its readers, and it might be just a matter of time before the company that publishes it joins the trend and has a change of name from Wimborne Publishing Limited to WPL.

I am not suggesting that abbreviations and acronyms are unnecessary, although there are probably some examples that fall into this category. In general though, they make it easier to stay brief and to the point and are helpful.

## Mistaken identity

There are potential problems with abbreviations, and perhaps more so with acronyms. The same ones can occur in more than one field of interest, which could lead to confusion. They have to be used where the context is clear, and the reader or listener understands whether (say) ESP means Spain, extrasensory perception, Email service provider, or is a company name.

A website that specialises in acronyms actually has over 150 definitions for ESP! Ideally, the full name or term should be included the first time an acronym or abbreviation is used, so that there is no ambiguity about its meaning.

The main problem is simply that acronyms and abbreviations will probably not mean a great deal to anyone who is new to a particular field of interest. I suppose the full versions of technical names and terms might not mean a great deal more to newcomers either. In this article we will consider some common abbreviations and acronyms used in electronics, their meaning, and practical significance.

## AC, DC and all that

It is likely that most non-technical people are aware that AC and DC mean 'alternating current' and 'direct current'. It is less well known that there are different types of alternating and direct current.

The simplest type of direct current is a source, such as a battery, that provides a more or less constant voltage. The current that flows depends on the demands of the load connected across the battery, but the most important point in this context is that the polarity of the battery and the current flow remain the same. Some DC sources provide a pulsed or varying voltage and current, but these are not AC sources because the polarity of the signal remains unaltered.

With an alternating current, the polarity of the source does change, and usually at regular intervals. One complete AC cycle consists of the current rising from zero with one polarity, falling back to zero, 'rising' with the opposite polarity, and falling back to zero again.

The number of complete cycles per second is the frequency of the signal. It is expressed in Hertz, and the standard abbreviation for Hertz is 'Hz'. The mains supply in the UK is at a frequency of 50Hz, and therefore has 50 complete cycles per second (in the US, it is 60Hz).

**Table 1: Commom acronyms associated with radio frequency signals**

| *Acronym* | *Meaning* |
|---|---|
| LF | low frequency (from about 30kHz to a few MHz) |
| VLF | very low frequency (from about 3kHz to 30kHz) |
| HF | high frequency (from a few MHz to 30MHz |
| VHF | very high frequency (from 30MHz to 300MHz) |
| UHF | ultra high frequency (from 300MHz to about 3GHz) |

## Frequency acronyms

There are several acronyms associated with AC signals, and these are used to describe approximate frequency ranges. The audio frequency (AF) range is generally accepted as covering about 20Hz to 20kHz, and someone with very good hearing can hear sound waves right to the top of this range.

Sound waves at higher frequencies are in the ultrasonic range, and are beyond the limits of human hearing, although some animals can perceive sounds well beyond the 20kHz upper human limit. Sounds at lower frequencies are in the infra-audio range, and can be detected as vibration rather that what could strictly be termed sounds.

Electronic signals at high frequencies are in the radio frequency (RF) range, but this is a very general term that covers everything from frequencies just beyond the audio range to those of many GHz (gigahertz). Consequently, there are other terms, and their acronyms are used to describe certain bands of frequencies within the radio range. The listing in Table 1 covers the common acronyms associated with radio frequency signals.

The practical importance of all this is that some types of components are designed to operate with one particular type of signal, and will not operate well if you try to use a different one. For example, transistors are usually designed for high or low frequency use. Transistors that are designed for audio and other low frequency applications are often capable of operating at frequencies up to the lower end of the UHF range, but they would be unlikely to provide really good performance at anything much beyond the audio spectrum.

Some low-tech components are designed specifically for DC use, or

over a particular range of frequencies. Cables and sockets for example, are mostly designed for a particular application. Connectors intended for operation at DC or in audio applications would be unlikely to operate well in RF applications. Connectors for use at high frequencies might actually work quite well at lower frequencies or even as DC power connectors, but it makes sense to use the right type of connector so that good performance and reliability is assured.

Fig.1. The plug on the left is a 75 ohm coax type intended for operation at VHF and UHF, and commonly used for television aerial leads. The phono socket on the right was designed for AF use, but is also used in RF applications such as carrying video signals

It is worth noting that with VHF and UHF signals it is often necessary to use a particular type of connector and cable, and not just the first ones you find that are intended for use at the upper end of the RF range. Cables and connectors for operation in VHF and UHF applications are specified as having a certain impedance, which is usually 50 or 75 ohms, and it is essential to use the right type.

The plug on the left in Fig.1 is a 75 ohm coaxial ('coax') type intended for use with UHF and VHF signals. The humble phono connector (Fig.1 right) is a simple type for use with audio equipment, but they are sometimes used in RF equipment. This is simply because they just happen to have the right characteristics for use at higher frequencies as well. I am not aware of any other type of connector that has this dual role.

## Poles apart

There are some common acronyms associated with switches, particularly the more simple types. They are often described as something like 'SPST' in components lists and component catalogues, which does not mean a great deal to the uninitiated; the acronyms associated with basic switches can be confusing initially. However, they are quite easy to understand. There are just four of them to contend with, and Table 2 shows all four abbreviations and their meanings.

A single-pole switch is a basic on/off type, and a double-throw switch is one that provides what is more commonly termed a changeover action. A changeover switch has three tags, and the middle one connects to one or other of the other two tags, depending on the setting of the switch. A single pole switch has just one set of contacts, whereas a double-pole type has two sets and is effectively two switches merged into one, with the two sections operating in unison.

The circuit symbols for all four types of switch are shown in Fig.2, and this also shows how the theoretical circuit symbols relate to most real-world switches. It has to be emphasised that the tag arrangements shown in Fig.2 are the most common ones, but there are some switches that use different layout.

With any switch of a type that you have not used before, it is best to use a continuity tester to determine which tag is, which rather than jumping to conclusions. It is also useful to bear in mind that a DPDT switch can be used to replace any of the other three types. For instance, if you ignore one set of three tags the other set will provide a SPDT switch. If you require (say) a SPDT slider switch, but can only find a DPDT type in the component catalogues, there should be no difficulty in using the DPDT component.

**Table 2: Commom acronyms for basic switches**

| *Acronym* | *Meaning* |
|---|---|
| SPST | single-pole, single-throw |
| SPDT | single-pole, double-throw |
| DPST | double-pole, single-throw |
| DPDT | double-pole, double-throw |

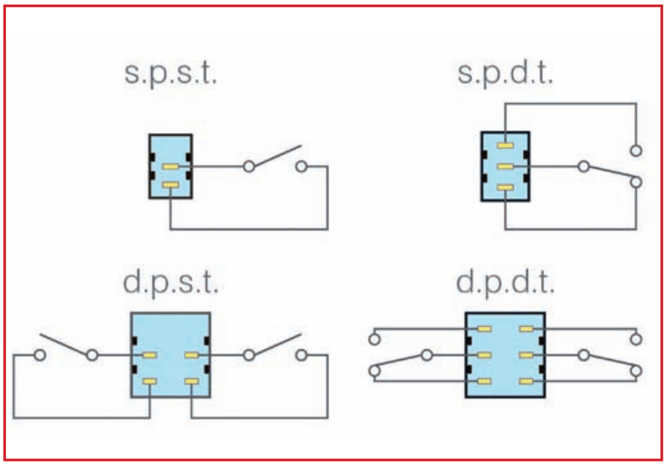



Fig.2. The four basic types of switch. A DPDT (double-pole, double-throw) type can be used instead of any of the others, and it is just a matter of ignoring the parts that are not required

## I see

There are plenty of acronyms associated with semiconductors, and in particular with ICs (integrated circuits). Strictly speaking, an integrated circuit is any semiconductor that has more than one component formed on the same chip. Some transistors have diodes and (or) resistors on the same chip to provide a degree of protection against static charges, but these are generally accepted as transistors rather than ICs, and are listed as such in component catalogues.

There seems to be an ever-growing range of acronyms associated with logic ICs. These are divided into two main families, which are the TTL and CMOS varieties. TTL stands for transistor-transistor logic, and it refers to the type of internal circuit fabrication technology used with these components. They mostly have type numbers starting '74' and are sometimes referred to as '74 series' chips, although some of the later devices have type numbers with '75' as the first two digits.

In the early days of logic ICs there were several rival technologies such as RTL (resistor-transistor logic) and DTL (diode-transistor logic), but most of these became obsolete many years ago. However, there are still some high speed ECL (emitter-coupled logic) devices in current use. The original TTL logic family soon spawned several improved

versions, but most of these, like the original TTL family, are now obsolete. The LS (low-power Schottky) family was the most successful, and these devices are still in use today.

The Schottky part of the name refers to a special type of diode used in this family of devices, which enables them to achieve fast operation at relatively low levels of current consumption. They have type numbers that start '74LS'.

The original CMOS (complementary metal oxide semiconductor) logic family is slow by modern standards, but was very popular in the past due to the low power consumption of these devices when operating at low frequencies. In fact, they consume no significant current at all when in a static state. They are still in use today, and have serial numbers starting at 4000.

Faster CMOS logic devices are now available, but perhaps a trifle confusingly, these have 74 series type numbers. For example, the 74HC4066 is the high-speed equivalent of the standard 4066 chip. The 'HC' in the type number indicates that it is a high-speed CMOS type.

There are also high-speed CMOS equivalents of some 74 series chips, and the 74HC08 for instance, is the high-speed CMOS version of the standard 7408 TTL chip. A letter 'T' included in the type number, such as 74HCT08, indicates that the device is a high-speed CMOS type, but it operates at TTL rather than CMOS supply and signal voltages.

Compatibility between the various logic families is not very good. Apart from other considerations, it has to be borne in mind that there are some substantial differences in the supply voltage ranges of the various types. Substituting an equivalent device from another logic family is not advisable unless you have the necessary technical expertise. A mistake could result in damage to the substitute device and other components in the circuit.

## Semiconductor line-up

Some of the acronyms associated with integrated circuits refer to their physical characteristics. Historically, the vast majority of integrated circuits used to have some form of DIL (dual in-line) encapsulation, and many still do so. They would normally have from 4 to 40 pins, in two rows that are 0.3 inches (7.62mm) apart on types having up to about 20 pins, and 0.6 inches (12.24mm) on the larger devices. The spacing between one pin and the next in each row is always 0.1 inches (2.54mm).

Some higher power semiconductors have a SIL (single in-line) encapsulation, which has only one row of pins. There was also a QIL (quad in-line) encapsulation having four rows of pins, but this was really just an ordinary DIL type with the pins shaped to create four rows. This type of encapsulation is now long obsolete.

These days encapsulation matters are complicated by the increasing use of surface mount (SM) components, including surface mount integrated circuits. Traditional components are mounted on the plain side of the board, with their pins or leads going through holes in the board so that they can be soldered to copper pads on the underside of the board.

However, with a surface-mount board there are no holes and the components are fitted on the copper side (see Fig.3). There are obvious physical differences between the two types, and the most obvious of these is that the surface-mount types are tiny in comparison to their conventional counterparts.

## On the surface

Surface-mount components have their own set of terms and acronyms. SMD (surface-mount device) is used to describe any component that is intended for surface mounting, including simple passive components such as resistors and largely mechanical components such as sockets. The encapsulations for integrated circuits have names such as SOIC (small-outline integrated circuit) and SSOP (shrink small-outline package).

Many components are now available in conventional and surface- mount versions, and in the case of integrated circuits they might also be available in more than one surface-mount encapsulation. When ordering components it is important to take due care in order to avoid accidentally ordering parts that are physically incompatible with the circuit board you will be using.

In the case of semiconductors, the type number usually has a suffix that indicates its case style. With the 741 operational amplifier for example, the suffix would usually be 'C' for the 8-pin DIL version in a plastic case, and 'W' for the ceramic Flatpack surface-mount version.

Unfortunately, the various semiconductor manufacturers do not all use exactly the same suffix for each case style. An 8-pin DIL component could have a 'C' suffix with one manufacturer, but an 'N' or 'CN' suffix from another. Any letters ahead of the basic part number usually indicate the manufacturer, such as LM for Nation Semiconductor and MC for Motorola.

This can be a bit confusing even for those used to dealing with semiconductor part numbers. However, component catalogues usually include basic details of each device, including the case style, so with due care it is possible to avoid ordering errors.

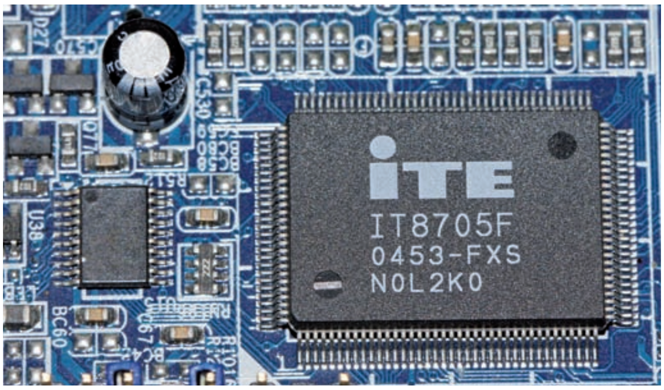



*Fig.3. SMT (surface-mount technology) has the components mounted on the copper side of the board. Unlike their conventional counterparts, surface-mount ICs often have pins on all four sides*

## Static-sensitive devices

There are acronyms associated with a special type of transistor called a FET (field-effect transistor). A 'JFET' or 'JUGFET' is a junction gate FET, and a MOSFET is a FET based on MOS (metal oxide semiconductor) technology. An important point to bear in mind is that any component that is based on MOS technology, including CMOS components, is very vulnerable to damage from static charges in the environment, and standard anti-static handling precautions should be observed when dealing with them.

These days, the majority of integrated circuits seem to be based on some form of MOS technology, so it is probably best to take a cautious approach and use anti-static precautions when dealing with any integrated circuit.

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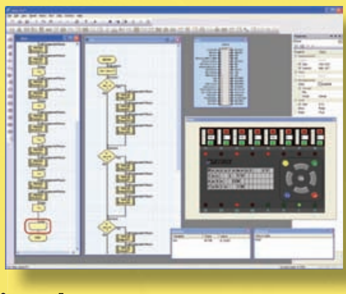

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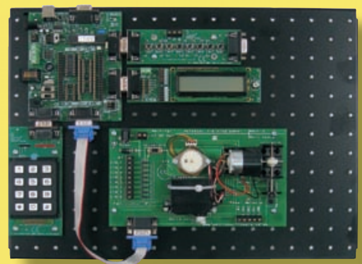

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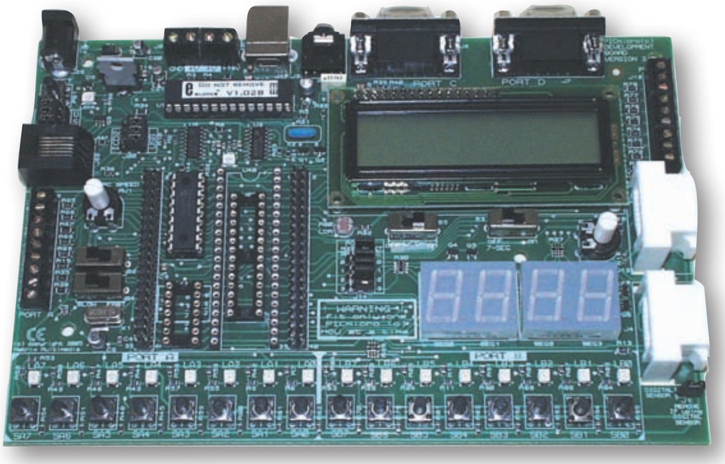

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## SOFTWARE

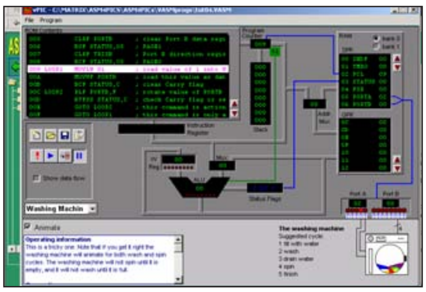
### ASSEMBLY FOR PICmicro V3

**(Formerly PICtutor)**

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84 PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

● Comprehensive instruction through 45 tutorial sections ● Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator ● Tests, exercises and projects covering a wide range of PICmicro MCU applications ● Includes MPLAB assembler ● Visual representation of a PICmicro showing architecture and functions ● Expert system for code entry helps first time users ● Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.) ● Imports MPASM files.

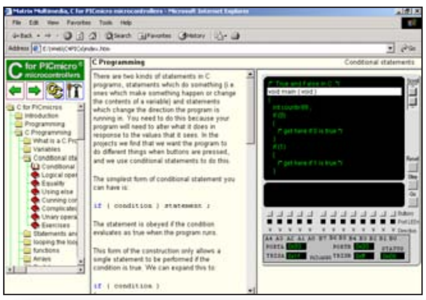


### 'C' FOR 16 Series PICmicro Version 4

The C for PICmicro microcontrollers CD-ROM is designed for students and professionals who need to learn how to program embedded microcontrollers in C. The CD-ROM contains a course as well as all the software tools needed to create Hex code for a wide range of PICmicro devices – including a full C compiler for a wide range of PICmicro devices.

Although the course focuses on the use of the PICmicro microcontrollers, this CD-ROM will provide a good grounding in C programming for any microcontroller.

● Complete course in C as well as C programming for PICmicro microcontrollers ● Highly interactive course ● Virtual C PICmicro improves understanding ● Includes a C compiler for a wide range of PICmicro devices ● Includes full Integrated Development Environment ● Includes MPLAB software ● Compatible with most PICmicro programmers ● Includes a compiler for all the PICmicro devices.



Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
Flowcode will run on XP or later operating systems

### FLOWCODE FOR PICmicro V4

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the Version 3 development board this provides a seamless solution that allows you to program chips in minutes.

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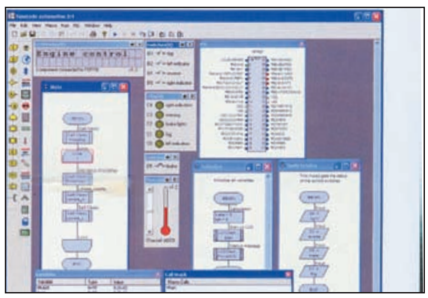
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces ASM code for a range of 18, 28 and 40-pin devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

New features of Version 4 include panel creator, in circuit debug, virtual networks, C code customisation, floating point and new components. The Hobbyist/Student version is limited to 4K of code (8K on 18F devices)



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**Prices for each of the CD-ROMs above are:**

*(Order form on next page)*

(UK and EU customers add VAT to 'plus VAT' prices)

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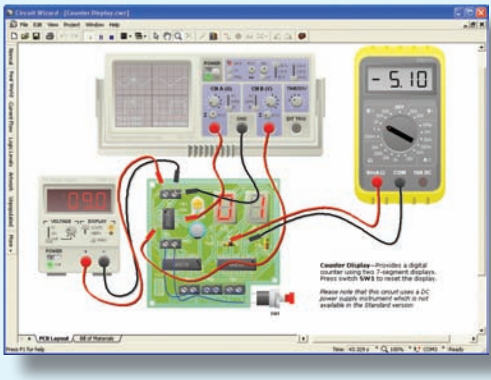

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Minimum system requirements for these CD-ROMs: Pentium PC, CD-ROM drive, 32MB RAM, 10MB hard disk space. Windows 2000/ME/XP, mouse, sound card, web browser.

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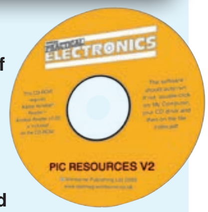


**Version 2 includes the EPE PIC Tutorial V2 series of Supplements (EPE April, May, June 2003)**

**The CD-ROM contains the following Tutorial-related software and texts:**

- EPE PIC Tutorial V2 complete series of articles plus demonstration software, John Becker, April, May, June '03
- PIC Toolkit Mk3 (TK3 hardware construction details), John Becker, Oct '01
- PIC Toolkit TK3 for Windows (software details), John Becker, Nov '01

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# READOUT

**Email: editorial@wimborne.co.uk**

**Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!**

All letters quoted here have previously been replied to directly


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## ★ LETTER OF THE MONTH ★

### The art of electronics

Dear Editor

Having just read Robert Penfold's excellent *Interface* (Feb'11) article on simple computer interfacing techniques, a thought struck me; rather than use Visual Basic, with its apparent paucity of sound-generating commands, it might be better to use one of the popular emulators such as RT Russell's excellent BBC Basic for Windows, in which a full range of sound commands are available. It would then be a simple matter of plugging in a tone decoder circuit into the headphone socket of the laptop or PC to provide as many control lines as are needed.

I do, however, love the simplicity of using the optical method; indeed, I'll probably use BBC Basic for Windows to control areas of the screen for the optical technique. It's because of exciting and thought-provoking ideas such as these that I find your magazine so rewarding to read.

As an artist who uses technology in sculpture and installations, one of the problems which I had to recently overcome was the opposite of last month's article – how to start Windows applications such as audio-files and media player from an external trigger. I'm sure that a more technically minded person could have solved the problem easily, but after much head scratching I achieved this by a combination of a doctored mouse in which a small relay replaced the middle switch and the use of the freely available Auto Hotkeys software, which enables the simple development of macros that can achieve the sequence of events one wishes. Total cost was £3.50!

Again, thank you for a great magazine, it has something for everyone, no matter one's level of ability or interest.

**Jon Davey, by email**
**Brea Village, Cornwall**

*Congratulations on your ingenious approach to starting a Windows program! I'm sure our readers could come up with dozens of alternative solutions, but cheap and simple works for me every time. Your sculpture and installations certainly sound interesting. Do you have any YouTube clips demonstrating your unique use of electronics which you would like to share with us?*

### Shedding light on switching

Dear Editor

In response to the letter from Enrico Figurelli (Jan'11), I am able to confirm that frequent switching of any lamp will generally cause degradation to its life cycle. However, the major recognised brands have improved their retrofit compact fluorescent products over recent years to a point where switching makes little, if any difference. There is even a 'facilities' version (for the facilities management market) available from one manufacturer specifically for frequently switched applications, which has a faster warm up time.

Some of these better versions are more expensive but, as ever, it is always better to select the right component for the application. The retail packaged, and very cheap, lamps seen in supermarkets are generally well suited to domestic use, where the light is left on for a moderate to long period.

**Dave Geary, by email**

*Many thanks for your input Dave. For those of you who are interested in fine control of lighting, don't miss next month's issue of* EPE *– one of our projects is the ultimate in dimmer projects!*

### Batman needs help!

Dear Editor

Thank you for providing us with your magazine since 1972! I work at Hugh Baird College in the UK, and we subscribe to your magazine (and have done for a very long time). Anyway, let's get to the rub. I am behind in providing a working circuit for my class (17 to 19 year-old physics applied) – we have chosen to work on the Rev Thomas Scarborough's *Bat Detector* (*EPE* March 2004).

We bought all the components and made 25 PCBs. We (well the electronics technician) assembled one of them and tested it (using a 40kHz transmitter on a simple 555 timer circuit). When the detector was turned on, a piercing tone was generated. When the transmitter was turned on – the signal was cut out. We rotated the transmitter (about 10cm from the receiver transducer) and the tone came back when the transmitter was pointed at right angles. Are you aware of this? I managed to contact Thomas, a very helpful fella, and he told me that the circuit published was a concept and that your technical guys had carried out a modification.

He also told me that he sent in a working model, which you published, but we can't find it (possibly due to the fact that some idiot has thrown out a stack of our copies when we changed labs). Is there any way you could help? – we are a bit desperate.

**Michael Dowling, by email**

*I'm very sorry to hear about your circuit problems Michael. I will hunt through my back issues and see if I can track down the piece you/Thomas referred to. In the meantime, if any readers have built this circuit and can help Michael and his students, then he can be contacted via the editorial office by email: enquiries@epemag.wimborne.co.uk.*

### PIC data to Excel

Dear Editor

In the December 2010 *Readout* section, the letter from Bob White asks about sending PIC data to MS Excel.

Fortunately, the answer is quite easy actually. Make sure the output from the PIC is in so called CSV format, and send it to a terminal program on the PC.

After receiving all data, save it in a file using the .CSV extension, then open it using MS Excel.

That's all there is to it.

**Harm de Vries (The Netherlands), by email**

*Thank you Harm, I hope that helps Bob and others with a similar PIC data-reading task*

GOT A QUESTION ABOUT *EPE* OR ELECTRONICS?
PLEASE EMAIL US AT:
**editorial@wimborne.co.uk**

# Net Work

Alan Winstanley

## A wireless world

Welcome to *Net Work* – the Internet column written for *EPE* readers. Regulars will recall that last year, after I started to experience various problems with my WiFi network, I replaced my flakey ADSL router with a less well-known, but cheaper type. I chose a Tenda W300D which was half the price of competing shrink-wrapped brands, my theory being that I would not mind so much if it needed replacing further down the line.

The wired Ethernet worked flawlessly as you would expect, but over time I started to experience intermittent 802.11 WiFi problems with the new router, with laptops, phones and Internet radios suddenly falling off the network every few months. This culminated with another outage last month that lasted over a day before it recovered. WiFi is a very funny thing: to the uninitiated the expectation is that a wireless router simply broadcasts from its little antenna, like a radio beacon which percolates throughout a structure where the signal will be found unfailingly by a WiFi laptop. I know one business user who demands that his wireless laptop connects to the office router first time, every time. He can't accept that WiFi technology simply does what it does, namely that it doesn't always work very well, especially when working inside a steel-clad industrial unit like his.

In practice, WiFi signals simply ricochet around inside a building following multiple paths, being reflected by some surfaces or absorbed by others. Human beings are basically big bags of water which block WiFi radio signals, as do copper wiring, steel girders and copper central heating fittings. With luck, and sometimes not a little experimentation, a half-decent signal will somehow bounce its way down one path or another and a successful connection will be made to your laptop or phone. Some routers have multiple internal antennae that improve connectivity. Wireless repeaters are available that extend the signal, too.

Sometimes it's worth visiting the website of your router's manufacturer to see if firmware updates are available that perhaps localise the router better for your country. You can usually flash the router using its control panel in a web browser, or use a separate utility program to upload the firmware onto the router via FTP. The process involves downloading a file from the web, maybe unzipping it, and simply pointing the firmware upgrade program to the router, ensuring that its power will not be interrupted during the update or you could end up with an expensive plastic brick tethered to your phone line.

## Not so neighbourly

Another frustrating WiFi issue is the increasing problem of conflicts caused by neighbours' networks. I can now detect three or four other networks (see **www.networkstumbler.com** for a useful utility) which funnily enough all seem to use Channel 1 by default. My own system is therefore nailed firmly in the middle on Channel 7 to help avoid interference; if WiFi problems are besetting you, consider switching to a different channel instead.

Several times my radio network failed altogether though, and after pulling what's left of my hair out and trying every trick in the book (short of hanging upside down from an upstairs window while holding a WiFi antenna between my teeth), it seemed that no amount of rebooting or resetting the slumbering Tenda router would restore the network. I checked the settings on devices such as my Pure Evoke WiFi radio, and saw that it had not been issued with an IP address (the display showed 0.0.0.0), and on several laptops I could see that only Windows' initial IP address (usually starting 169.254….) was configured (type **ipconfig** from the Windows command prompt to see).

In effect, my stubborn WiFi network was going half-blind periodically. Depending on a few options, these 'temporary' IP addresses are usually superseded when the router issues its own IP address to each peripheral on the network, and so after a minute or two I would expect to detect a series of unique IPs, each starting 192.168... It's the job of the router's DHCP server (if used) to issue IP addresses to every node and this clearly wasn't happening. Each address also has a 'lease' or period configured in the router after which it is renewed.

Nothing could be done to force the network to start up properly. Only once I powered everything down overnight did I find that the network re-built itself next morning and WiFi devices would burst into life as expected. How frustrating!

```
C:\WINDOWS\system32\cmd.exe
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\ARW>ipconfig

Windows IP Configuration


Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        IP Address. . . . . . . . . . . . : 192.168.0.101
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.0.1

Ethernet adapter Bluetooth Network Connection:

        Media State . . . . . . . . . . . : Media disconnected

C:\Documents and Settings\ARW>_
```

*Typing IPCONFIG at a Windows command prompt reveals basic details of your network connection. The computer's unique IP address here is 192.168.0.101, which is issued by the router's DHCP server. The 'gateway' is the router's own IP address, in this case 192.168.0.1*

## Hot spots

A check on Tenda's website highlighted a firmware upgrade to 'address DHCP' issues, which I hoped would resolve the problem. Despite this, I found that WiFi was still somewhat inconsistent and sometimes bothersome, though some of this is due to environmental reasons.

Furthermore, I pondered the Tenda and couldn't help noticing how hot the always-on router became in normal use. As you'd expect from an electronics nut, I soon found myself musing over the ventilation provided, and came to the conclusion that it could probably be better. A quick squirt with a laser infra-red thermometer showed that its housing reached nearly 45°C in places. I use the keyhole slots on the underside to hang the router vertically from the courtesy panel of my desk, well out of the way, but this does mean that heat percolates upwards over the whole router.

One can't be too critical of these types of peripheral though. As I've mentioned in the past, the shelves of computer stores are lined with glossy computer products, each seductively shrink-wrapped in eye-catching display cartons, and that's the rub: many computer products are consumer-level devices. They have high 'showroom appeal' but are simply not designed or built for always-on use and they don't last for ever. Over in my worklab I have a whole pile of routers that have all failed: usually it's the power supply, or an Ethernet port, or the WiFi radio fails.

In next month's *Net Work,* I'll introduce more router basics and describe how I overcame my problems with a more radical upgrade, benefitting my wired Ethernet at the same time. You can email me at **alan@epemag.demon.co.uk** or share your views with the editor for possible publication in *Readout*, by writing to **editorial@wimborne.co.uk**.

NEW

## Electronics Teach-In 3

FREE CD-ROM

The three sections of this book cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on various circuit design and application problems – everything from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered.

Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 different circuit designs submitted by the readers of *EPE*.

The free cover-mounted CD-ROM is the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial), together with simulations of the circuits in the Teach-In 1 series, plus Flowcode (a limited version) a high level programming system for PIC microcontrollers based on flowcharts.

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC. There is also a MW/LW Radio project in the series.

The contents of the book and Free CD-ROM have been reprinted from past issues of *EPE*.

*160 pages+CD-ROM* **Order code ET3** **£8.50**

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### USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has now been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

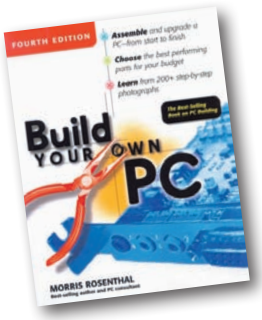
Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers.

An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

The Microchip items are: MPLAB Integrated Development Environment V8.20; Microchip Advance Parts Selector V2.32; Treelink; Motor Control Solutions; 16-bit Embedded Solutions; 16-bit Tool Solutions; Human Interface Solutions; 8-bit PIC Microcontrollers; PIC24 Micrcontrollers; PIC32 Microcontroller Family with USB On-The-Go; dsPIC Digital Signal Controllers.

*CD-ROM* **Order code ETI2 CD-ROM** **£9.50**




### BUILD YOUR OWN PC – Fourth Edition
**Morris Rosenthal**

More and more people are building their own PCs. They get more value for their money, they create exactly the machine they want, and the work is highly satisfying and actually fun. That is, if they have a unique beginner's guide like this one, which visually demonstrates how to construct a computer from start to finish.

Through 150 crisp photographs and clear but minimal text, readers will confidently absorb the concepts of computer building. The extra-big format makes it easy to see what's going on in the pictures. The author goes 'under the hood' and shows step-by-step how to create a Pentium 4 computer or an Athlon 64 or Athlon 64FX, covering: What first-time builders need to know; How to select and purchase parts; How to assemble the PC; How to install Windows XP. The few existing books on this subject, although outdated, are in steady demand. This one delivers the expertise and new technology that fledgling computer builders are looking for.

*224 pages - large format* **Order code MGH2** **£16.99**

### PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C – LEARNING TO FLY THE PIC24 Lucio Di Jasio (Application Segments Manager, Microchip, USA)

A Microchip insider tells all. Focuses on examples and exercises that show how to solve common, real-world design problems quickly. Includes handy checklists to help readers perform the most common programming and debugging tasks. FREE CD-ROM includes source code in C, the Microchip C30 compliler, and MPLAB SIM software, so that readers gain practical, hands-on programming experience.

Until recently, PICs didn't have the speed and memory necessary for use in designs such as video- and audio-enabled devices. All that changed with the introduction of the 16-bit PIC family, the PIC24. This new guide teaches readers everything they need to know about the architecture of these chips, how to program them, how to test them and how to debug them. Lucio's common-sense, practical, hands-on approach starts out with basic functions and guides the reader step-by-step through even the most sophisticated programming scenarios.

Experienced PIC users and newcomers alike will benefit from the text's many thorough examples, which demonstrate how to nimbly side-step common obstacles and take full advantage of all the 16-bit features.

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Among the topics covered are: A brief overview of the various versions of Windows 7. How to install and use Upgrade Advisor, which checks to see if your computer meets the minimum requirements to run Windows 7 and that your software and drivers are supported by Windows 7. How to use Windows Easy Transfer to migrate your data and settings from your Vista or XP machine to your new Windows 7 computer. Exploring Windows 7 so that you will become familiar with many of its new features and then see how they contrast with those of earlier versions of Windows. How to connect to a network and create and use Home Groups to easily share your pictures, videos, documents, etc.,with the minimum of hassle. Why Windows Live Essentials is so useful and how to download and install it. A brief introduction to Windows Media Center. The use of Action Center, which reports security and maintenance incidents. Windows Memory Diagnostic to detect the fairly common problem of faulty memory and Troubleshooting tools.

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**HOW TO BUILD A COMPUTER MADE EASY**
**R.A. Penfold**
Building your own computer is a much easier than most people realise and can probably be undertaken by anyone who is reasonably practical. However, some knowledge and experience of using a PC would be beneficial. This book will guide you through the entire process. It is written in a simple and straightforward way with the explanations clearly illustrated with numerous colour photographs.

The book is divided into three sections: *Overview and preparation* – Covers understanding the fundamentals and choosing the most suitable component parts for your computer, together with a review of the basic assembly. *Assembly* – Explains in detail how to fit the component parts into their correct positions in the computer's casing, then how to connect these parts together by plugging the cables into the appropriate sockets. No soldering should be required and the only tools that you are likely to need are screwdrivers, small spanners and a pair of pliers.

*BIOS and operating system* – This final section details the setting up of the BIOS and the installation of the Windows operating system, which should then enable all the parts of your computer to work together correctly. You will then be ready to install your files and any application software you may require.

The great advantage of building your own computer is that you can 'tailor' it exactly to your own requirements. Also, you will learn a tremendous amount about the structure and internal workings of a PC, which will prove to be invaluable should problems ever arise.

*120 pages* **Order code BP707** **£8.49**

**AN INTRDUCTION TO eBAY FOR THE OLDER GENERATION**
**Cherry Nixon**
eBay is an online auction site that enables you to buy and sell practically anything from the comfort of your own home. eBay offers easy access to the global market at an amazingly low cost and will enable you to turn your clutter into cash.

This book is an introduction to eBay.co.uk and has been specifically written for the over 50s who have little knowledge of computing. The book will, of course, also apply equally to all other age groups. The book contains ideas for getting organised for long term safe and successful trading. You will learn how to search out and buy every conceivable type of thing.The book also shows you how to create auctions and add perfect pictures. There is advice on how to avoid the pitfalls that can befall the inexperienced.

Cherry Nixon is probably the most experienced teacher of eBay trading in the UK and from her vast experience has developed a particular understanding of the issues and difficulties normally encountered by individuals.

So, if you are new to computers and the internet and think of a mouse as a rodent, then this is the book for you!

*120 pages* **Order code BP709** **£8.49**

**GETTING STARTED IN COMPUTING FOR THE OLDER GENERATION**
**Jim Gatenby**
You can learn to use a computer at any age and this book will help you acheive this. It has been especially written for the over 50s, using plain English and avoiding technical jargon wherever possible. It is lavishly illustrated in full colour.

Among the many practical and useful subjects that are covered in this book are: Choosing the best computing system for your needs. Understanding the main hardware components of your computer. Getting your computer up and runnning in your home. Setting up peripheral devices like printers and routers. Connecting to the internet using wireless broadband in a home with one or more computers. Getting familiar with Windows Vista and XP the software used for operating and maintaining your computer. Learning about Windows built-in programs such as Windows Media Player, Paint and Photo Gallery.

Plus, using the Ease of Access Center to help if you have impaired eyesight, hearing or dexterity problems. Installing and using essential software such as Microsoft Office suite. Searching for the latest information on virtually any subject. Keeping in touch with friends and family using e-mail. Keeping your computer running efficiently and your valuable data files protected against malicious attack.

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**Mike Tooley**
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The book's content is matched to the latest pre-degree level courses, making this an invaluable reference for all study levels, and its broad coverage is combined with practical case studies, based in real-world engineering contexts throughout the text.

The unique combination of a comprehensive reference text, incorporating a primary focus on practical applications, ensures this text will prove a vital guide for students and also for industry-based engineers, who are either new to the field of electronics, or who wish to refresh their knowledge.

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Contents: Fundamental concepts; Analog versus digital; Conductors and insulators; Voltage, current, resistance, capacitance and inductance; Semiconductors; Primitive logic functions; Binary arithmetic; Boolean algebra; Karnaugh maps; State diagrams, tables and machines; Analog-to-digital and digital-to-analog; Integrated circuits (ICs); Memory ICs; Programmable ICs; Application-specific integrated circuits (ASICs); Circuit boards (PWBs and DWBs); Hybrids; Multichip modules (MCMs); Alternative and future technologies.

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A highly practical introduction for hobbyists, students, and technicians. Keith Brindley introduces readers to the functions of the main component types, their uses, and the basic principles of building and designing electronic circuits.

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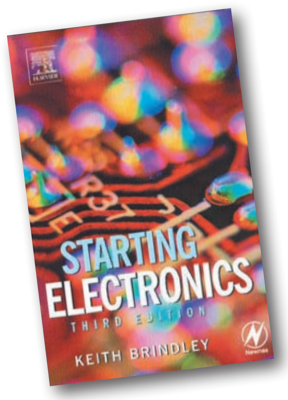

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There are faders, wipers and effects units which will add sparkle and originality to your video recordings, an audio mixer and noise reducer to enhance your soundtracks and a basic computer control interface. Also, there's a useful selection on basic video production techniques to get you started.

Complete with explanations of how the circuit works, shopping lists of components, advice on construction, and guidance on setting up and using the projects, this invaluable book will save you a small fortune.

Circuits include: video enhancer, improved video enhancer, video fader, horizontal wiper, improved video wiper, negative video unit, fade to grey unit, black and white keyer, vertical wiper, audio mixer, stereo headphone amplifier, dynamic noise reducer, automatic fader, pushbutton fader, computer control interface, 12 volt mains power supply.

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### ELECTRONIC PROJECT BUILDING FOR BEGINNERS
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**Morgan Jones**

The practical guide to building, modifying, fault-finding and repairing valve amplifiers. A hands-on approach to valve electronics – classic and modern – with a minimum of theory. Planning, fault-finding, and testing are each illustrated by step-by-step examples.

A unique hands-on guide for anyone working with valve (tube in USA) audio equipment – as an electronics experimenter, audiophile or audio engineer.

Particular attention has been paid to answering questions commonly asked by newcomers to the world of the vacuum tube, whether audio enthusiasts tackling their first build, or more experienced amplifier designers seeking to learn the ropes of working with valves. The practical side of this book is reinforced by numerous clear illustrations throughout.

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The projects include:- Simple audio links, F.M. audio link, P.W.M. audio links, Simple d.c. links, P.W.M. d.c. link, P.W.M. motor speed control, RS232C data links, MIDI link, Loop alarms, R.P.M. meter.

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**NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail. Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS**.

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# EPE EVERYDAY PRACTICAL ELECTRONICS

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## Miscellaneous

**VALVES AND ALLIED COMPONENTS IN STOCK.** Phone for free list. Valves, books and magazines wanted. Geoff Davies (Radio), tel. 01788 574774.

**KITS, TOOLS, COMPONENTS. S.A.E. Catalogue.** SIR-KIT ELECTRONICS, 52 Severn Road, Clacton, CO15 3RB, **http://sir-kit.webs.com**

# EVERYDAY PRACTICAL ELECTRONICS

## NEXT MONTH

### 45-SECOND VOICE RECORDER MODULE

Here's a fun and easy-to-build voice recorder that can record two, four or eight different messages. It provides clean and glitch-free line-level audio output suitable for feeding an amplifier or PA system. For ultimate flexibility you can even set the audio quality / length of message ratio.

### PIR-TRIGGERED MAINS SWITCH

Most domestic PIR systems just switch on lights – this project uses PIR sensors to switch any mains-powered device rated up to 10A. It comes with user-adjustable on-time, manual override and fits in a neat, tough box.

### MULTI-FUNCTION, INTELLIGENT REMOTE-CONTROLLED DIMMER

This has got to be the ultimate dimmer project! It works with incandescent and dimmable CFL (compact fluorescent) lights, as well as some 12V halogen lights. Provides mood and home-theatre lighting, all controlled with a standard handheld remote controller.

### QUICK'N'EASY DIGITAL SLIDE 'SCANNER'

Got a drawer full of slides? This quick and easy project uses a point-and-shoot digital camera to 'scan' them into your computer in a fraction of the time taken by expensive, slow 'pro' scanners!

### TEACH-IN 2011 – PART 6

Mike and Richard Tooley continue our indispensable back-to-basic series with a look at digital logic circuits.

**APRIL '11 ISSUE – ON SALE 10 MARCH**

**Content may be subject to change**



## ADVERTISERS INDEX



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*For Editorial address and phone numbers see page 7*



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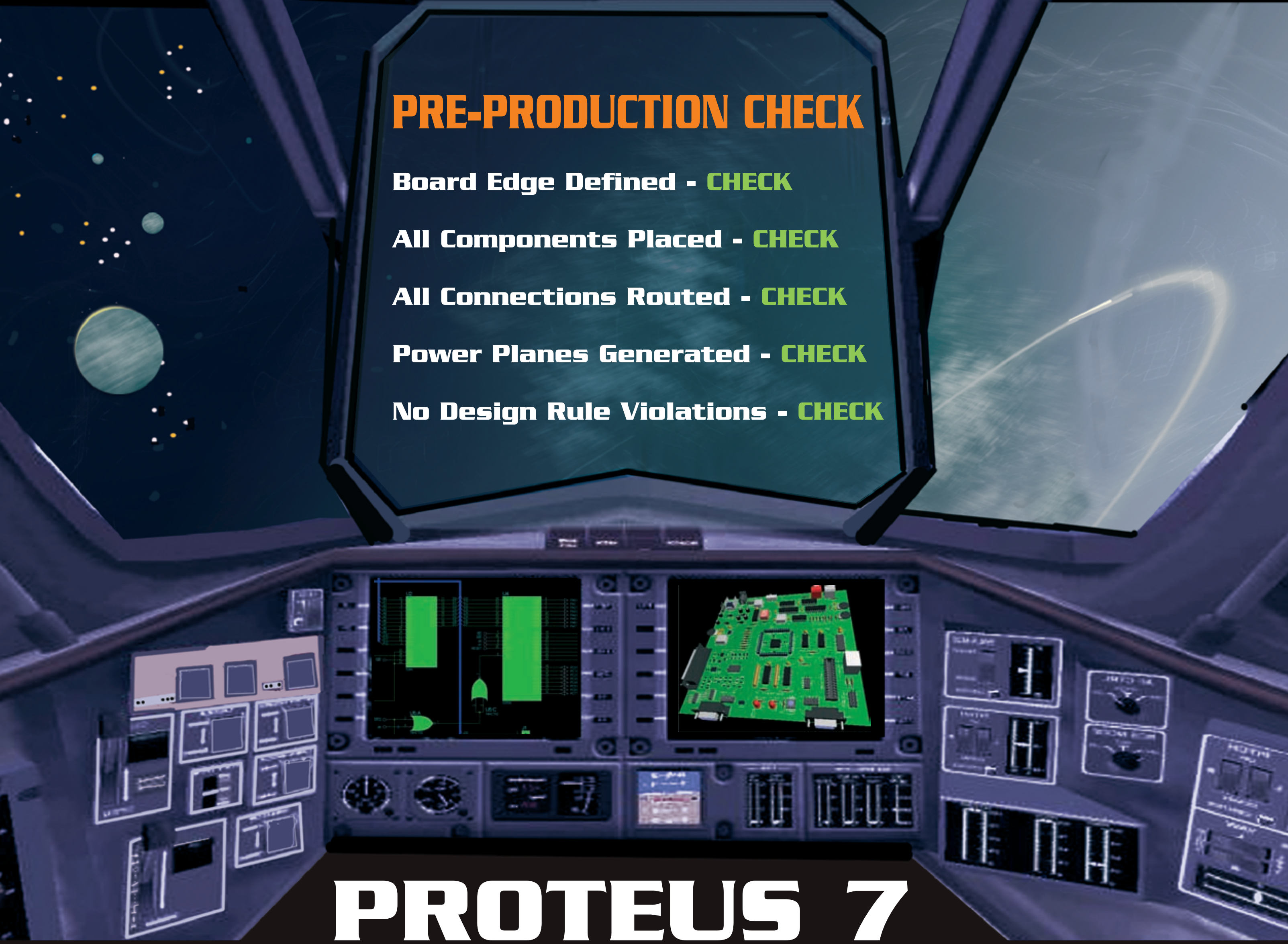
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